REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	21.May.03	THESIS

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
HUMAN ERROR ANANLYSIS OF FATAL GENERAL AVIATION ACCIDENTS, 1990-1998, APPLICATION OF A REVISED TAXONAMY OF UNSAFE ACTS	
6. AUTHOR(S) CAPT FAABORG TROY P	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) UNIVERSITY OF ILLINOIS AT URBANA	8. PERFORMING ORGANIZATION REPORT NUMBER CI02-930
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) THE DEPARTMENT OF THE AIR FORCE AFIT/CIA, BLDG 125 2950 P STREET WPAFB OH 45433	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Unlimited distribution In Accordance With AFI 35-205/AFIT Sup 1	

13. ABSTRACT *(Maximum 200 words)*

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20030604 066

14. SUBJECT TERMS	15. NUMBER OF PAGES
	115
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

THE VIEWS EXPRESSED IN THIS ARTICLE ARE THOSE OF THE AUTHOR AND DO NOT REFLECT THE OFFICIAL POLICY OR POSITION OF THE UNITED STATES AIR FORCE, DEPARTMENT OF DEFENSE, OR THE U.S. GOVERNMENT

University of Illinois
at Urbana-Champaign

Department of Psychology

603 East Daniel Street
Champaign, IL 61820

217-244-5876 *fax*

College of Liberal Arts
and Sciences

May 8, 2003

TO WHOM IT MAY CONCERN:

Troy Faaborg was enrolled as a graduate student in the Department of Psychology at the University of Illinois at Urbana-Champaign. Troy Faaborg successfully deposited his Masters Theses on April 30, 2003. The Masters of Science degree will be awarded to him at the May 18 degree conferral. If you have any questions regarding Troy Faaborg's degree progress, please feel free to contact Lori Hendricks at the Graduate Student Affairs Office at (217) 333-2169 or email lhendric@s.psych.uiuc.edu.

Sincerely,

Edward J. Shoben
Professor and Head of Psychology

Cheryl Berger

Cheryl A. Berger
Assistant Head of Graduate Affairs

Karl R. Rosengren
Associate Head of Graduate Affairs

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

GRADUATE COLLEGE

May 2003
date

WE HEREBY RECOMMEND THAT THE THESIS BY

Troy Philip Faaborg

ENTITLED Human Error Analysis of Fatal General Aviation Accidents, 1990-1998; Application of a Revised Taxonomy of Unsafe Acts

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science

Douglas A. Wiegmann
Director of Thesis Research

Edward J. Skoufas?
Head of Department

Committee on Final Examination†

Chairperson

†Required for doctor's degree but not for master's.

O-517

HUMAN ERROR ANALYSIS OF FATAL GENERAL AVIATION ACCIDENTS, 1990-1998; APPLICATION OF A REVISED TAXONOMY OF UNSAFE ACTS

BY

TROY PHILIP FAABORG

B.S., Iowa State University, 1998

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2003

Urbana, Illinois

To Jennifer, Noah, and Jonas

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Civil flights (non-military) in the United States (U.S.) are classified as either General Aviation (GA) or air carrier operations. General aviation activities include recreational flying, flight instruction, agricultural operations, sightseeing, and business travel (Li & Baker, 1999). The aircraft involved in GA flying may be piloted by a variety of people with a valid pilot license and approved medical history, but belonging to a wide range of age groups. The aircraft flown by GA pilots include airplanes, helicopters, balloons, and gliders.

Each year, the National Transportation Safety Board (NTSB) records about 2000 GA crashes, which claim about 750 lives (National Safety Council, 1997). Between 1990-1996, GA accounted for 93% of all aviation crashes and 78% of all aviation fatalities. In fact, a pilot flying under the auspices of general aviation is nearly 10 times more likely to be involved in an accident than a military air crewmember (USAF, 2003), more than 11 times more likely than a commercial air crewmember (NTSB 2003b; NTSB, 2003c), and almost 50 times more likely to be involved in a fatal crash than large scale commercial pilots (NTSB, 2003a).

Perhaps even more sobering is the observation that the fatal crash rate per 100,000 flight hours for GA has changed very little over the past decade (National Safety Council, 1997) and many safety professionals have expressed little hope that great strides in GA safety will be forthcoming in the near future. A major reason for this general lack of improvement in GA accident rates is that

most accidents are due, at least in part, to pilot error, rather than more objective and tangible issues such as mechanical and systems failures. Most air safety investigators have engineering and technical backgrounds, with little formal training in human factors. Furthermore, accident investigation systems and their associated databases have not been designed to specifically address human error or its innumerable causes. Consequently, most GA accident investigations focus more on what the pilot did wrong rather than why the error occurred. As a result, the development of interventions for reducing the occurrence and consequences of pilot error has been onerous (Shappell & Wiegmann, 1996).

The present thesis is part of a larger research program aimed at improving GA safety through the development of a theoretical framework for investigating and analyzing human error during accident investigations. The specific purpose of this study is to analyze the nature and prevalence of different forms of human causal factors associated with general aviation accidents by using an analytical framework grounded in cognitive psychology and theoretical models of human error. The results of this study will provide insight into the types of errors associated with GA accidents and may provide information can then be used to develop timely and effective aviation safety and accident prevention programs. The results could also provide future input into design of a human factors accident investigation system that is more firmly grounded in human error theory.

Before discussing the specific findings of this study, however, a review of the various ways of describing human error will be presented along with a general description of the basic information processing model upon which most contemporary theories of human error are based. Given the decision making process is a central component to many models of human error (e.g. Reason, 1990) and has been shown to play a major role in fatal aviation accidents (O'Hare, Wiggins, Batt, & Morrison, 1994), this component of the information processing model will be address in more detail. Next, models of human error will be presented, as well as a review of how such models have been used to classify errors associated with aviation accidents. Specific hypotheses concerning the results of the present study will then be presented.

Methods For Describing Human Error

A vast array of human error taxonomies have been published by myriad authors in many fields, and are often developed for use within a very narrow scope of behavior that is being analyzed by the researcher. This compliment of classification methods reflects the spectrum of research orientations from the highly practical to the highly theoretical, as well as a range from high task specificity to broad claims about error tendency and predisposition. Reason (1990) contends that most error taxonomies can be parsed into three levels of error: the behavioral, contextual, and conceptual levels.

Behavioral level. This level is considered to be the most superficial means of describing error as it classifies actions according to easily observable features

of performed actions. Features commonly identified include formal characteristics of error such as omission, commission, repetition, and misordering, or the immediate consequences (extent of damage or injury) brought about by erroneous actions. When describing performance in terms of inappropriate actions, examples of errors could include "valve was not closed completely," "airspeed was excessive," or "landing gear was not extended." While perhaps appealing due to its objective and thus parsimonious nature, a behavioral classification system fails to account for the fact that many different causal mechanisms can result in the same behavioral error class and that different behavioral categories may share common causes (Norman, 1981; Reason & Mycielska, 1982; Reason, 1984).

Contextual level. Describing error at the contextual level goes beyond surface error characteristics and makes limited assumptions about error cause. Everyday slips of the tongue or pen are often described within the scope of contextual errors, with mild assumptions and reference to triggers in the immediate environment. Within aviation such factors as phase of flight, weather status, and environmental conditions are examples of contextual descriptions of the "where" and "when" of error that are not captured through a behavioral classification method. The benefit of the contextual level is the consideration of the conditions that prompt errors at particular times or in certain circumstances. While quite useful, contextual descriptions of error are limited in that they cannot

by themselves account for the fact that the same or very similar conditions do not always elicit the same error forms.

Conceptual level. The third level of error description, a conceptual level of classification, is based upon assumptions and theories about the cognitive mechanisms involved in error genesis. Since the conceptual level is based in large part on theoretical inferences about cognitive function and less on observable characteristics of error or their context, analysis of error is carried out at a deeper level of assumption and conjecture. Despite the risk of these assumptions, classifications grounded in conceptual considerations have the greatest potential for error reduction as they seek to group errors of a similar nature and identify the underlying mechanisms that are the origins of those errors. The forthcoming analysis of general aviation errors is made at the conceptual level classification as we ultimately seek to determine underlying error mechanisms and causal factors for the purpose of accident and incident mitigation and improved safety. Before effective classification can occur, however, the conceptual process underlying human error must be more formally described.

Cognition Defined: The Information Processing Model

Although not specifically failure models, information processing theories serve as the foundation of most conceptual models of human error. According to Card, Moran, and Newell (1983), information processing occurs in three general stages: the acquisition of information, the making of decisions and plans, and the

implementation of action. Principle features if this and other information processing models is the assumption of stages of mental operations in the process, and research is directed at isolating and characterizing each. Attributes of stages include capacity (how much information can be used or stored at a given time or span of time), duration (how long information can be stored), and form of representation (how the information is coded). While a simple model to understand, the Card, Moran, and Newell model does not allow for the full richness and complexity of human behavior, and yields no insight into creative, whimsical, or emotionally driven behavior. Further, the model assumes goodwill on the part of the individual, and irresponsible or illogical behavior is not accounted for.

A four-stage model of information processing has been proposed by Wickens and Hollands (2000; see Figure 1). A principle feature of this model is the assumption that information progresses through a series of four stages, viewing the pilot as the information processor. The stages are sensory processing using the short term sensory store, perception, response selection, and response execution. Also included in the model is the construct of situation awareness through management of attention resources, involving perception, working memory, and long term working memory, a concept of great importance in the dynamic domain of aviation.

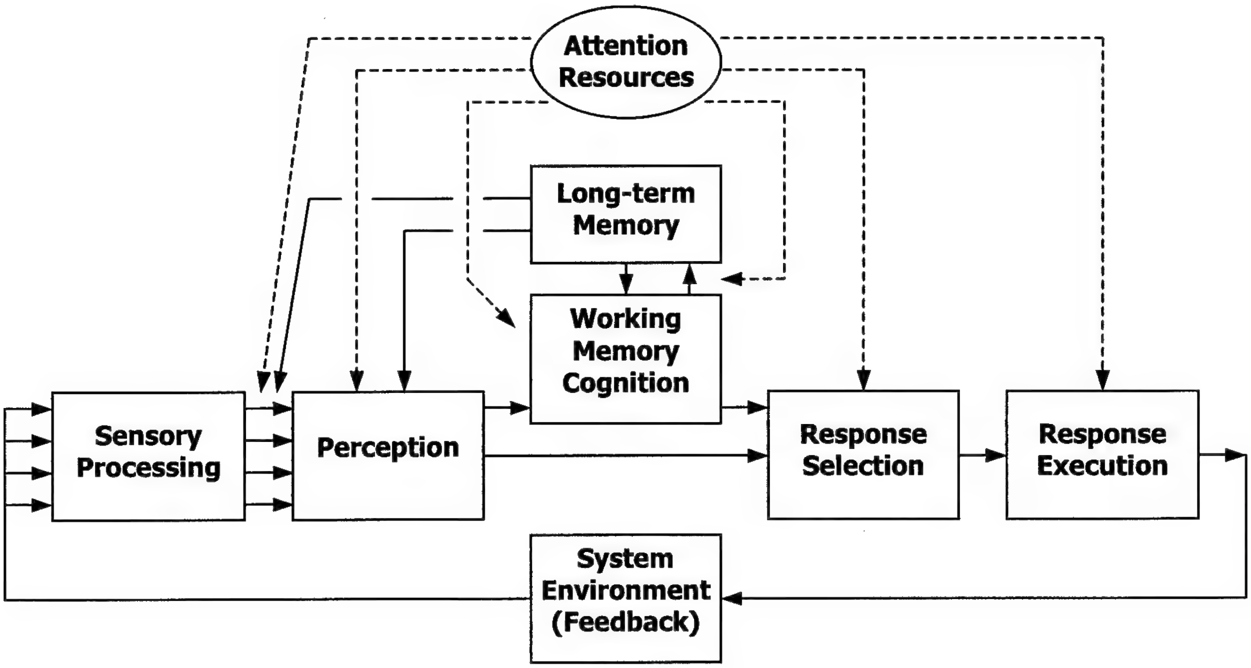

FIGURE 1: Information Processing Model

Various features of stimuli enter the senses, are perceived, and are stored temporarily while they undergo a process of pattern recognition and are integrated into meaningful elements. There is a short term sensory store for each sensory modality where physical energy such as light or sound is transformed into neural energy by anatomical structures including the rods, cones, and tympanic membrane. This information lasts only a short time, less than one second for visual information, and does not require attention resources.

Perception is one of the most important stages in the model, where the chaos of physical stimuli is integrated into meaningful elements. Light patterns are recognized as words and ideas, patterns of waves and vibrations are interpreted as sounds and messages, and a specific pattern of stimulus flow can

be recognized as a particular aircraft altitude and attitude. Contributing to the complexity of perception and pattern recognition is the reality that many physical codes may map to a single pattern or memory, and a single physical stimulus may map to many patterns or memory codes. As a result, perceptual processes are often limited by the supply of attention resources available. As an illustration, consider the pilot who is under a high workload during the landing sequence of approach and is not attending to the radio communications that come through the headset. Attention may be captured by the mention of the aircraft call sign over the radio, so even this "unheard" information may be receiving deeper analysis.

The stage of decision and response selection occurs when a stimulus has been recognized and a choice must be made as to what to do about it. Options at this stage include storing the information for future use (in the short term sensory store, working memory, or long term memory), integration of the new information with other available information, or a response to the stimulus. The costs and benefits of each option are considered in the process of choosing among them. The decision making oval presented in the model is made up of some perception, working memory, and the information represented in this response selection stage.

Following the selection of response is response execution. If the option chosen at the decision stage is to initiate action or motor response, this intention must be translated into a coordinated series of motor commands. It is during

this stage that generally specified intentions must be translated into precisely sequenced muscle commands.

Individual attention and memory resources influence processing in the latter three stages of the model. The feedback loop allows for outputs to be monitored and adjusted as necessary. Resulting action at the response execution stage becomes the input to the sensory stores that is interpreted and considered as data relevant to selecting the next response. As a closed loop model, the process may begin at any point, but typically progresses from left to right as presented in Figure 1.

The Decision Making Process

Decision making is often pivotal to effective information processing, particularly while performing a complex task such a piloting an aircraft, as research of aviation accident data that will be discussed indicate. Consequently, most conceptual models of human error focus heavily on addressing failures in decision-making processes. Therefore, before discussing specific error models, this section provides a more through description of the decision-making process than was provided in the previous discussion of the general information processing perspective.

The process of decision making is given three general characteristics: the evaluation of sources of information, the probability of information, and the value and cost associated with the decision (Wickens & Flach, 1988). In order to evaluate information, a consideration must be made of several sources in order

to assess the situation and understand the current state of the world. This assessment forms the basis for choosing an action appropriate for each situation. The information that an aviator deals with is often probabilistic. For example, when a weather service forecasts an 80% chance of rain, a 20% chance that it will not rain complements it. Thus, the projected consequences of an action into the future are uncertain, and due to the probabilistic nature of information even a correct decision can produce an unfortunate outcome and likewise a poor decision may "luck out." Value and cost underlie most decisions, and each decision must be made by balancing its potential benefit with its potential cost. The model of decision making presented by Wickens & Hollands (2000) is one example of a graphical illustration of the decision process and is presented in Figure 2.

Within the context of decision making theory are other areas of concern such as decision making heuristics and biases, decision framing, and poor judgment chains. Heuristics, mental rules of thumb that help to reach a diagnosis without an excess of mental effort, can make decision makers overlook such important statistical variables as sample size, prior probabilities, and critical correlations. While they often work very well, heuristics are simply shortcuts in the decision making process and therefore allow room for errors to occur. Even if time is not a factor, the decision maker still may not utilize all available information as cue seeking is limited by the characteristics of human attention (Wickens, 1984; Wright, 1974).

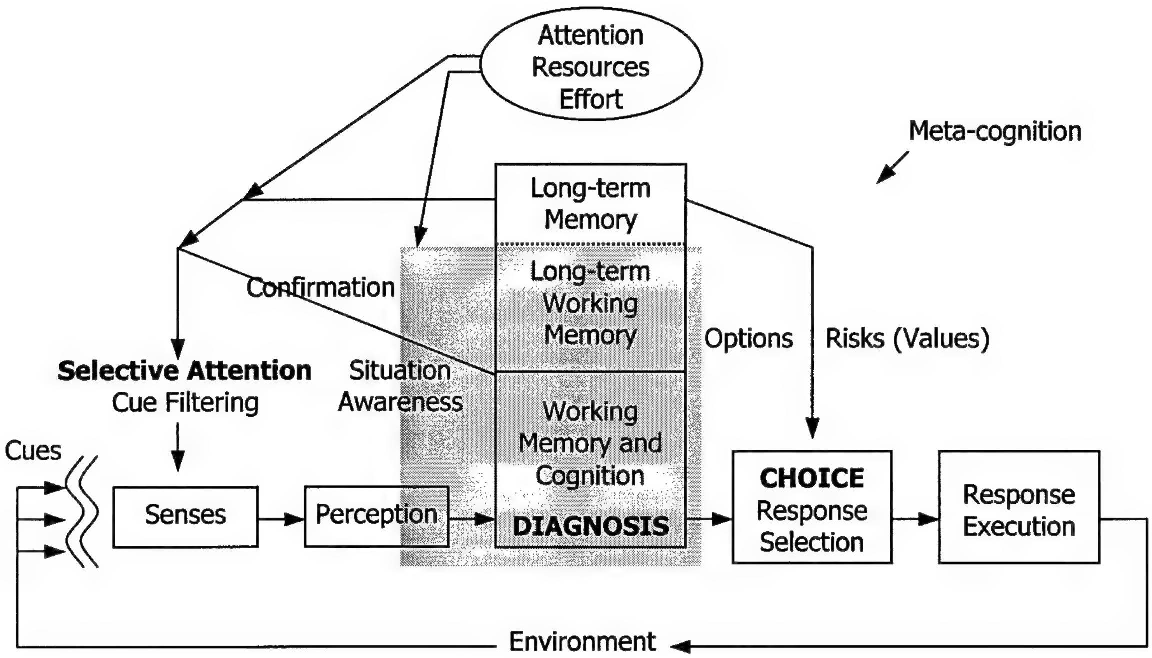

FIGURE 2: Decision Making Model

The representativeness heuristic involves trying to understand a situation by matching in working memory the pattern of cues seen in the environment with a mental representation of the typical pattern for a particular situation as recalled in long term memory (Tversky & Kahneman, 1974). Representativeness results in a tendency to judge the likelihood of an event based upon the similarities it shares with a familiar event, whereas availability refers to judging events' probabilities depending on the ease with which instances can be remembered (Nagel, 1988). The resulting availability heuristic is noted by the consideration of a hypothesis as most likely if it is most available in memory. While most available may not mean most probable but instead most recent, most

simple, or otherwise, a decision maker must accurately use probability or base rate frequency information as a guide to their decision. If a decision maker treats all information as if it is of equal reliability, they incorporate the "as if" heuristic, and they may fail to devalue information that is less reliable (Johnson, Cavenaugh, Spooner, & Samet, 1973).

The salience bias occurs when a decision maker focuses on a limited number of physically salient symptoms or cues, yielding a bias toward salience at the expense of information content. There sometimes occurs a bias to seek, and therefore find, sources of information confirming that which we already believe to be true, known as the confirmation bias (Mynatt, Doherty, & Tweney, 1977; Wason & Johnson-Laird, 1972). A decision maker can also be influenced by the manner in which the decision is framed (Tversky & Kahneman, 1981). The choice between two actions, one a risk and one a sure thing, will depend very much upon whether the problem is framed as a choice between gains or a choice between losses.

Orasanu (1993) further emphasizes the role of problem definition in a model of decision making based on a taxonomy of decision types (Figure 3).

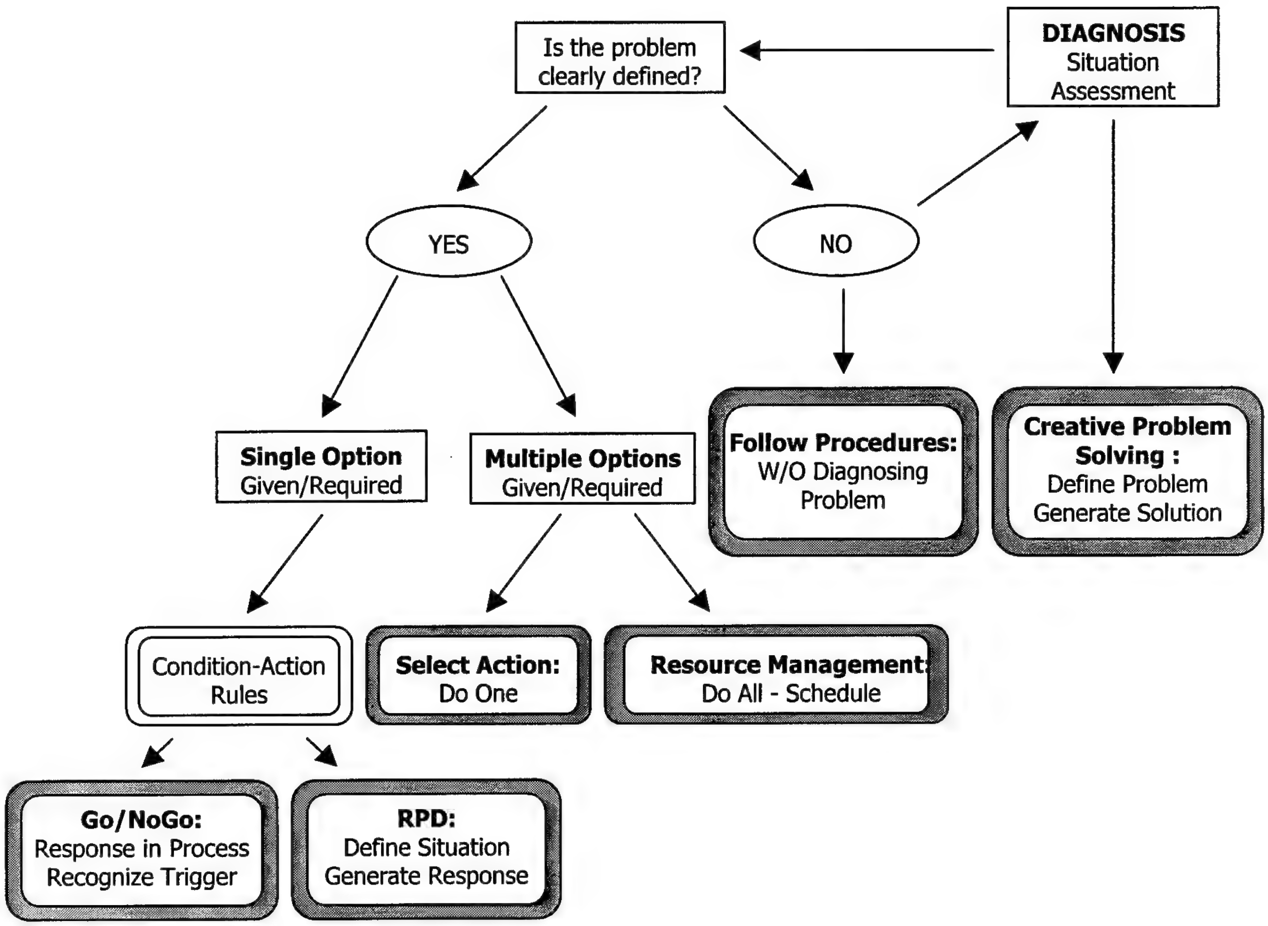

Figure 3: Orasanu's taxonomy of decision types.

Classification of decisions, according to this model, is based upon whether a problem is clearly defined or ill defined. Clearly defined problems involve decision tasks that differ in the information available about response options and are classified as single response or multiple response.

Some situations require only a single response, sometimes described as a condition-action pair, and are therefore quite simple since they require minimal

cognitive work by the decision maker. Single option decisions, similar to rule-based decisions (Rasmussen, 1982; Reason, 1990) are further divided by Orasanu into two types of condition-action rules. The "Go/No Go" decision type simply involves a decision as to whether or not an action should be initiated or terminated. A recognition primed decision (RPD), on the other hand, is one that often requires a response, but this response is clearly defined by a procedure or rule given the specific nature of the problem. When the problem is clearly defined and there is only one option to follow, RPD's simply require the generation and implementation of the appropriate response.

Multiple response option decisions, on the other hand, parallel the knowledge based decisions described by Reason (1990) and Rasmussen (1982) and are also divided into two types. Option selection decisions involve the case when an operator is presented with multiple options and must choose the one thought to be the most appropriate for the given problem. Conversely, resource management decisions are necessary when an operator is faced with multiple options, all of which must be performed within a specified and often limited amount of time. These decisions are often described as scheduling decisions involving resource allocation and management.

Within the scope of ill defined problems, two options exist when conditions are not clarified in the process of diagnosing the situation. An operator may elect to manage and diagnose a situation as though it is an emergency without clearly defining the problem, or they could diagnose and

define the problem and then implement a solution. The latter is much more complex as prescribed procedures do not exist for solving the problem, and ambiguity of conditions often precludes the definition of a single correct or most appropriate solution.

Finally, Jensen (1995) and others (e.g., Reason, 1990; Wickens & Hollands, 2000) have also pointed out that the decision making process can also be strongly influenced by human emotion and motivation. For example, pilots might be influenced by what Jensen calls background factors or motivational forces that keep operators from following purely rational decision-making processes. Some of these issues include motivational factors such as economic concerns, commitment, social pressures, and ego involvement, as well as physiologically driven aspects such as fatigue or illness. Therefore, since humans by their nature tend to base their decisions, at least in part, on such motivational and emotional factors, such variables also need to be considered when examining decision-making behavior.

Models of Human Error

Numerous models of the human error have been proposed over the years. These models differ in terms of the underlying psychological mechanism that presumably produces an error. Some such models have been based on personality theory and the concept of accident proneness, while other error models have been based on Freudian psychoanalytical theory and the idea that errors reflect misplaced manifestations of unfulfilled subconscious desires

(Haddon, Suchman, & Klein, 1964). However, contemporary models of human error are most often grounded in cognitive and information processing theories, such as those theories proposed by Rasmussen (1982) and Reason (1990).

Rasmussen (1982) proposed a theory of human error often referred to as the Skills-Rules-Knowledge (S-R-K) model. Reason (1987) incorporated this model into his generic error modeling system (GEMS, see Figure 4), which he then later expanded into his model of unsafe acts (1990). This latter model is presented in Figure 5 and illustrates that unsafe acts can be broken down into intended and unintended actions. This does not mean that errors are either intended or unintended because individuals typically not set out to make an error. Rather, it is the act and underlying cognitive processes that are either intentional or unintentional. Both intended and unintended actions can be further broken down into more detailed categories. These will be described the following sections.

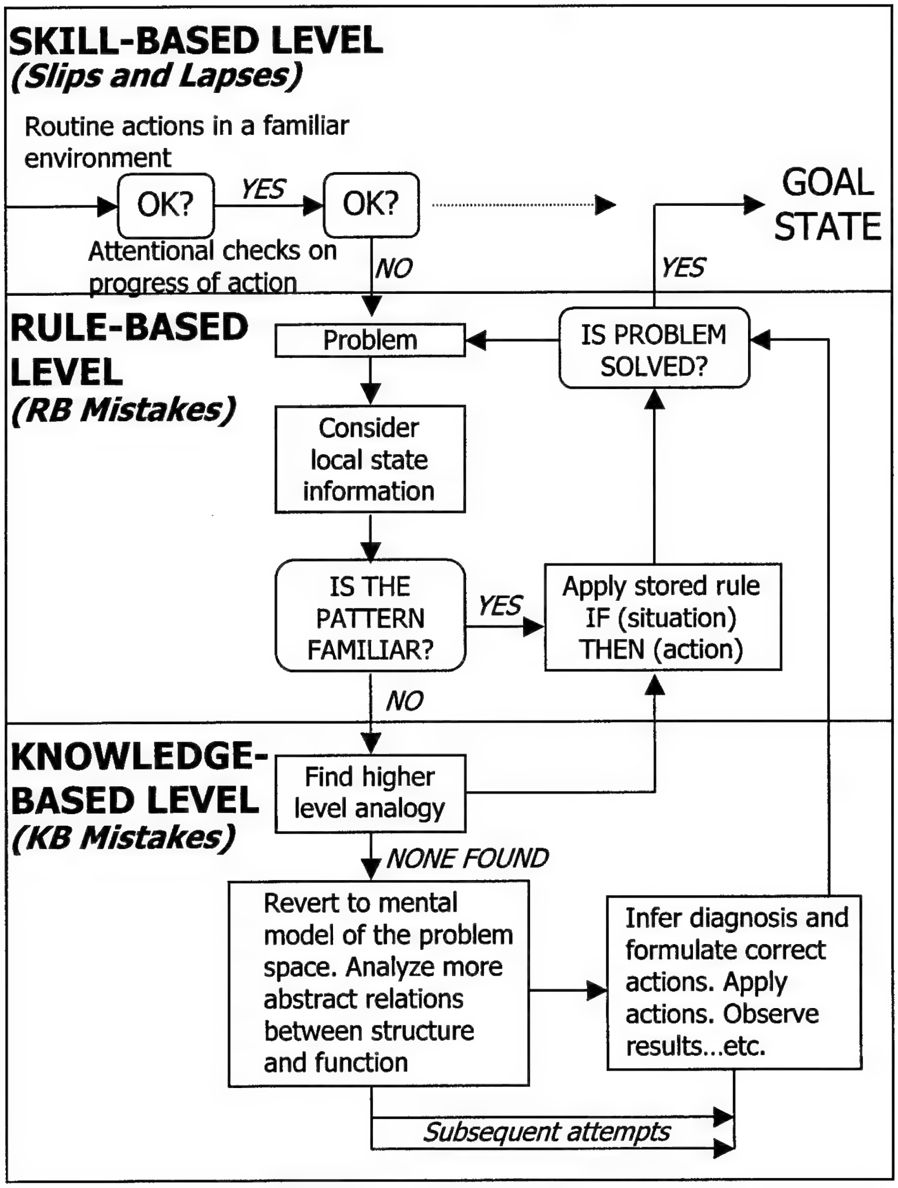

FIGURE 4: Generic Error Modeling System (GEMS)

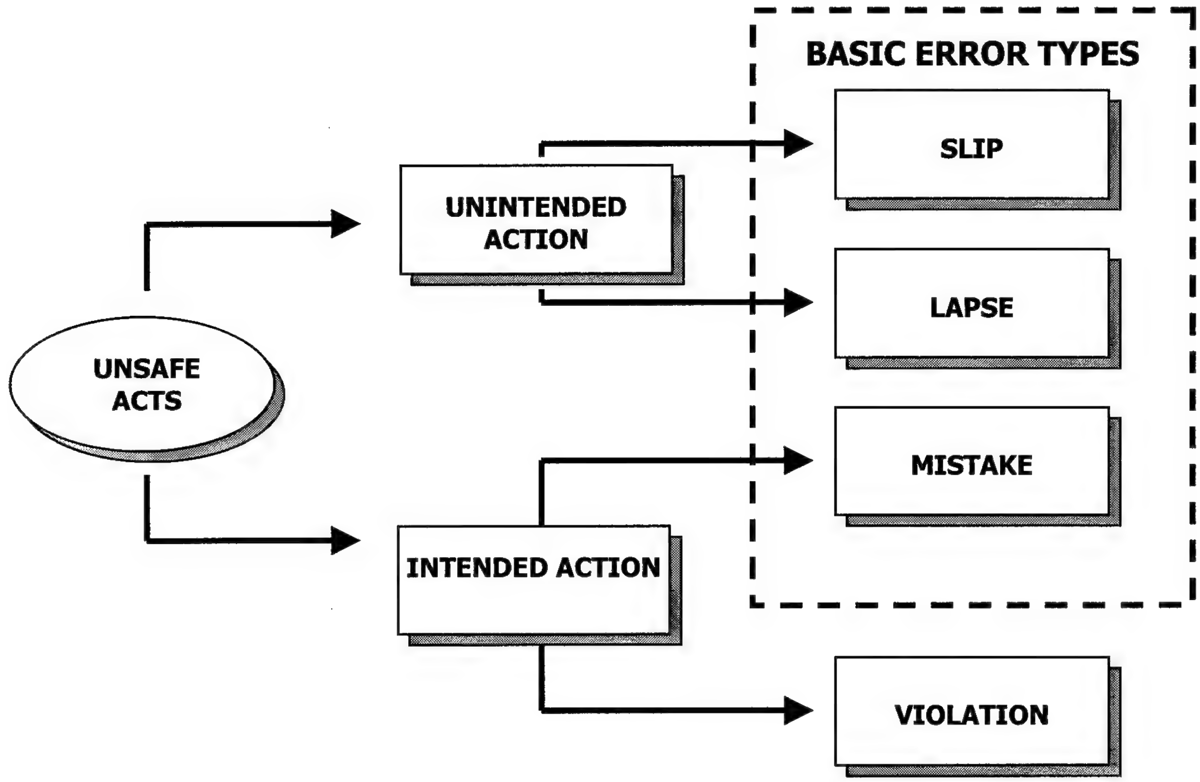

FIGURE 5: Reason's Model of Unsafe Acts

Unintended actions. Unintended actions are comprised of what Rasmussen (1988) originally described as skill-based errors, consisting of two types. The first type of error is classified as mental slips, such as inadvertently adjusting flaps when lowering the landing gear was intended. These errors are due primarily to attention failures and manifest themselves in the action phase of behavior (Rasmussen, 1983). Other examples of actions classified as slips are double capture slips, reduced intentionality, interference error, and perceptual confusion

Double capture slips are errors that occur during performance of a well-practiced activity. In a double capture slip, there is intention to depart from the routine, but due to a failure to check attention, habit intrusion results (Reason & Mycielska, 1982; Reason, 1984). Reduced intentionality involves a delay that intervenes between formulation of an intention and action execution. Perhaps we have all encountered this error when we walk into a room only to realize that we have forgotten what we went there for. Interference errors are the entanglement of two currently active plans, or two actions within a plan, each struggling for control, and are sometimes called blends or spoonerisms after the late Reverend William Archibald Spooner (Hayter, 1976). Perceptual confusion occurs during highly routine sets of actions when recognition schemata accept as a match for the proper object something that looks like it or does a similar job. Intending to take the carton of milk from the refrigerator but taking out the orange juice carton instead demonstrates perceptual confusion.

The second type of unintended action is lapses, typically referring to more covert errors involving failures of memory that do not necessarily manifest themselves in actual behavior (Sellen, 1994; Maurino, Reason, Johnston, & Lee, 1995; Reason, 1997). An example of a lapse is the failure to tighten a bolt after a maintenance procedure (Reason, 1997). Further examples of lapses, due to what Rasmussen calls "overattention," can be classified as omissions, repetitions, or reversals (Rasmussen, 1982).

Omissions are defined as situations where a person is interrupted while performing a task and a mistimed check of status yields the conclusion that a process is further along than it is. As a consequence, the mistimed status check results in the omission of one or more necessary steps in the process. An example is the reception of a phone call during the composition of an email and the resultant sending of the message without including the intended attachment. In a similar vein, repetition occurs in the same situation, but instead one determines that a process has not yet reached the point where it actually is and thus repeats actions already accomplished. In the error of reversal, an inappropriately timed check causes the action sequence to be doubled back upon itself. Each of these types of errors represents an example of mistimed monitoring.

Intended actions. Intended actions are divided into two broad categories called mistakes and violations. Mistakes are further subdivided into rule-based and knowledge-based mistakes (Rasmussen, 1982; Reason, 1990).

Rule based failures involve either the misapplication of good rules or the application of bad rules. Good rules are defined as those with proven utility and can be misapplied in a number of ways. The cues used to determine whether or not a rule should be employed include signs which satisfy some to all conditional aspects of an appropriate rule, counter-signs indicating that the more general rule is inapplicable, and non-signs that do not relate to any existing rule and

constitute noise. Such conditions are similar to Orasanu's (1993) distinction between clearly defined and ill-defined problems that was described previously.

Situations that should invoke exception to a general rule do not necessarily declare themselves in an unambiguous manner, particularly in complex, dynamic problem solving tasks. The first occasion that an individual encounters a significant exception to a general rule, particularly when the rule is reliable, a "strong but now wrong" error of first exception occurs. It is, however, only through such errors that we begin to discover the full range of situational variation. Information overload can occur when an abundance of information confronts a problem solver and attentional resources can only process a limited amount of incoming stimuli. Further, a remarkably stubborn tendency toward applying familiar and cumbersome solutions when simpler, more elegant solutions are readily available is referred to as rigidity, about which Reason speaks when he declares "to a person with just a hammer, every problem looks like a nail" (1990, p. 78)

Application of bad rules occurs either due to misrepresented environmental features or unsuitable response action, and can be separated into the two classes of encoding deficiencies and action deficiencies. In deficiencies of encoding, certain properties of the problem may be coded inaccurately or may not be encoded at all, or an erroneous general rule may be protected by the existence of domain specific exception rules where the exception proves the rule. Conversely, action deficiencies fall within a continuum of performance that spans

from inefficient to outright wrong, and take the form of wrong rule use, inelegant or clumsy action where multiple routes lead to the same solution, or inadvisable rules that are appropriate in some circumstances but can create problems when employed regularly (Reason, 1990).

Knowledge based errors are the result of limitations in processing the incoming information from physical environmental stimuli. Error of selectivity is the term given to mistakes that occur if attention is given to the wrong features (or not given to the right features) of the environment, such as can be the case when the problem solver's attention is directed to logically important rather than psychologically salient aspects. Working memory limitations often contribute to knowledge based error in that often the working memory operates by a "first in, first out" principle wherein it is easier to recall items in the order in which they were presented. The availability heuristic, the idea of "out of sight, out of mind," occurs when undue weight is given to facts readily at hand and ignores those not immediately in mind.

In the face of ambiguity, one may rapidly favor an available interpretation of incoming cues, and may then be reluctant to part with it. Termed the confirmation bias, this knowledge based error has its roots in Bartlett's 1932 "Effects after meaning." Similarly, problem solvers and planners alike are prone to overconfidence in evaluating the correctness of their knowledge and may justify a chosen course of action by focusing on evidence that favors it and disregarding contradictory signs. Particularly in a complex task such as aviation,

problem solvers encounter feedback delay, difficulty dealing with exponential development, and intellectual emergency reaction.

The other type of intended action within the model of unsafe acts is the violation. Violations are not errors per se, rather they represent willful disregard for rules and regulations and reflect the motivation component of human judgment descried earlier (e.g., Jensen, 1995). Such violations according to the model of unsafe acts may be habitual behaviors generally tolerated by the organization (routine violations) or isolated occurrences of unsafe behavior that is considered unacceptable departures from authority (exceptional violations). A common example of a routine violation is the habitual breaking of the speed limit by a few miles per hour while driving. While by law a violation, it is rare to be pulled over and given a citation for exceeding the speed limit by a very small amount. Widespread oversight of this minor infraction effectively endorses this behavior as being considered acceptable to the operator. When routine violations are identified, investigators must look up the causal chain and identify those individuals in authority who have not enforced established rules.

An exceptional violation, such as exceeding the speed limit by 40 miles per hour, while perhaps horrendous and appalling, is not considered to be exceptional due to its extreme nature. Instead, a violation that is neither typical of the individual nor condoned by authority is termed exceptional, making it difficult to predict and problematic for organizations to deal with. If a violation is deliberate it is considered sabotage, whereas if there is no prior intention to

commit the violation it is considered to be an unintended or erroneous violation. Most occur within a middle ground between these points, errors which are intentional to a degree but without the goal of system damage.

Error Analysis of Accident and Incident Data

Recently, several researchers have attempted to develop human error frameworks to aid in the classification, description, and analysis of errors associated with aviation accidents. Many of these frameworks are based on general cognitive models of human error, as well as more detailed models proposed by Rasmussen (1982) and Reason (1990). For example, O'Hare et al. (1994) expanded upon the traditional information-processing model using Rasmussen's S-R-K model and developed a six-step sequence for analyzing the underlying cognitive failures associated with an error (Figure 6). The second step and the last step are roughly equivalent to the short-term sensory store and response execution stages of the traditional information processing model already described. The four mediating steps expand upon the remaining two information processing stages of pattern recognition and decision selection, as the algorithm includes diagnostic, goal setting, strategy selection, and procedure adoption stages.

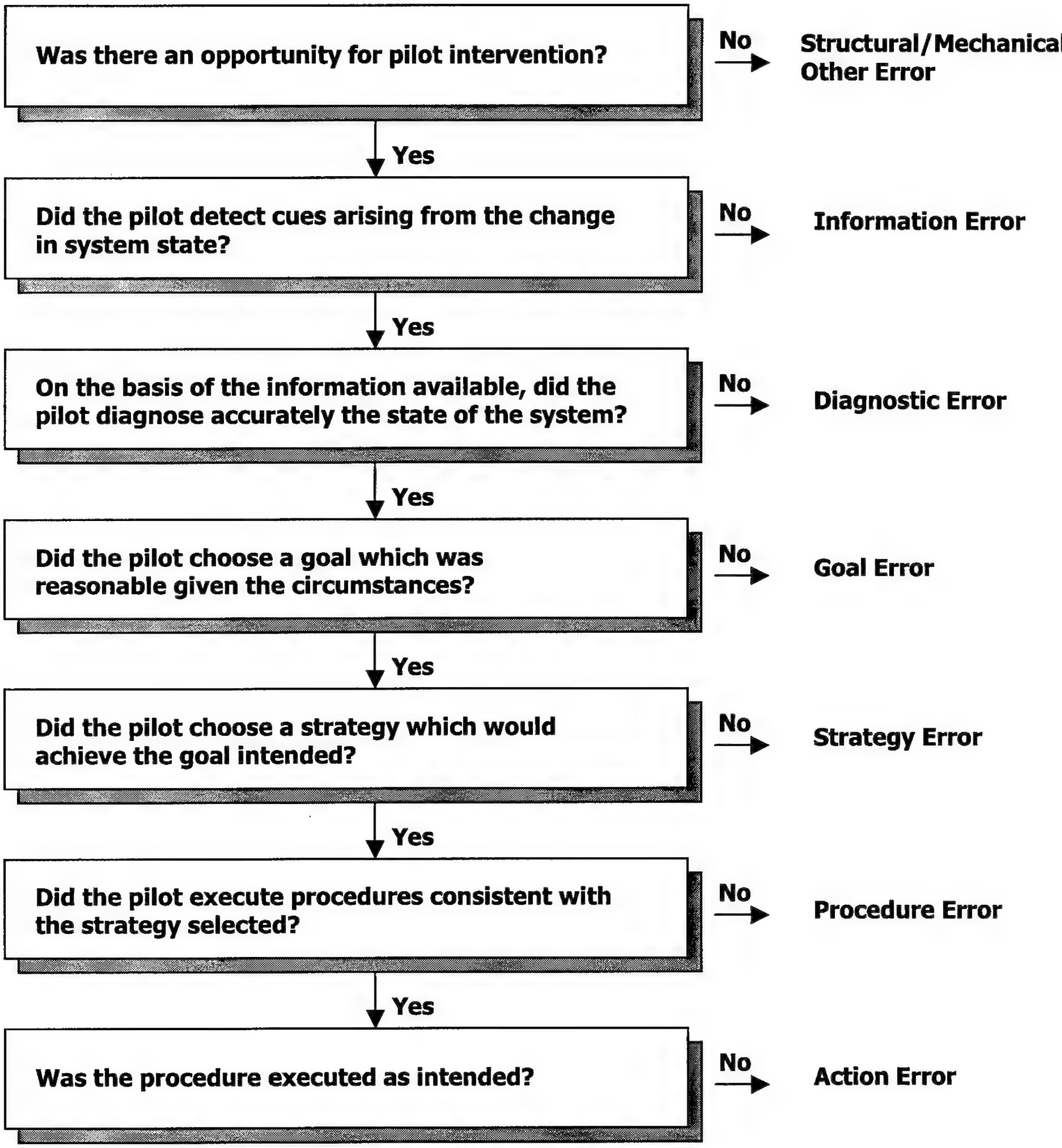

FIGURE 6: O'Hare et al. Six Step Algorithm

O'Hare et al. used this framework to classify causal factors associated with accidents and incidents involving New Zealand civil aircraft between 1982 and 1991. Their results revealed that 71% of the coded mishaps were associated with a form of human error, with the most prevalent error form being action errors (43%), followed by decision errors (35%) and information errors (22%). Fully 62.5% of fatal crashes involved decision errors on the part of the aircrew whereas only 30.5% of non-fatal accidents involved such errors. This finding supports the seminal work in this area by Jensen and Benel (1977) that suggests that fatal aviation accidents are more likely to be due to poor decision making by the pilot.

Sarter and Alexander (2000) present an error analysis model (Figure 7) that is based on Rasmussen's S-R-K framework as well as Reason's Model of Unsafe Acts. Employing this model, the authors analyze NASA Aviation Safety Reporting System (ASRS) incident reports involving passenger flights on 14 CFR Part 121 (commercial) carriers in terms of the formal characteristics of underlying errors as well as the cognitive and performance stages in which errors occurred.

Errors were first classified three broad categories including errors of omission (lapses), or errors of commission (slips) and mistakes. They were also further categorized by performance level into skill based, rule based, or knowledge-based mistakes. The analysis performed by Sarter and Alexander reveals that, similar to O'Hare et al., (1994) the largest percentage of errors

examined occurs at the action or skill-based level of performance (75.8%) followed by rule-based and knowledge-based errors (14.3% and 9.8%, respectively). The authors concluded that the skill based level findings reflect basic memory and attention failures on part of the aircrew and suggest that automation that compensates for attention and memory problems in pilot performance. Sarter and Alexander further propose that this type of automated facilitation of pilot abilities to monitor aircraft systems and the general flight environment may be needed (2000).

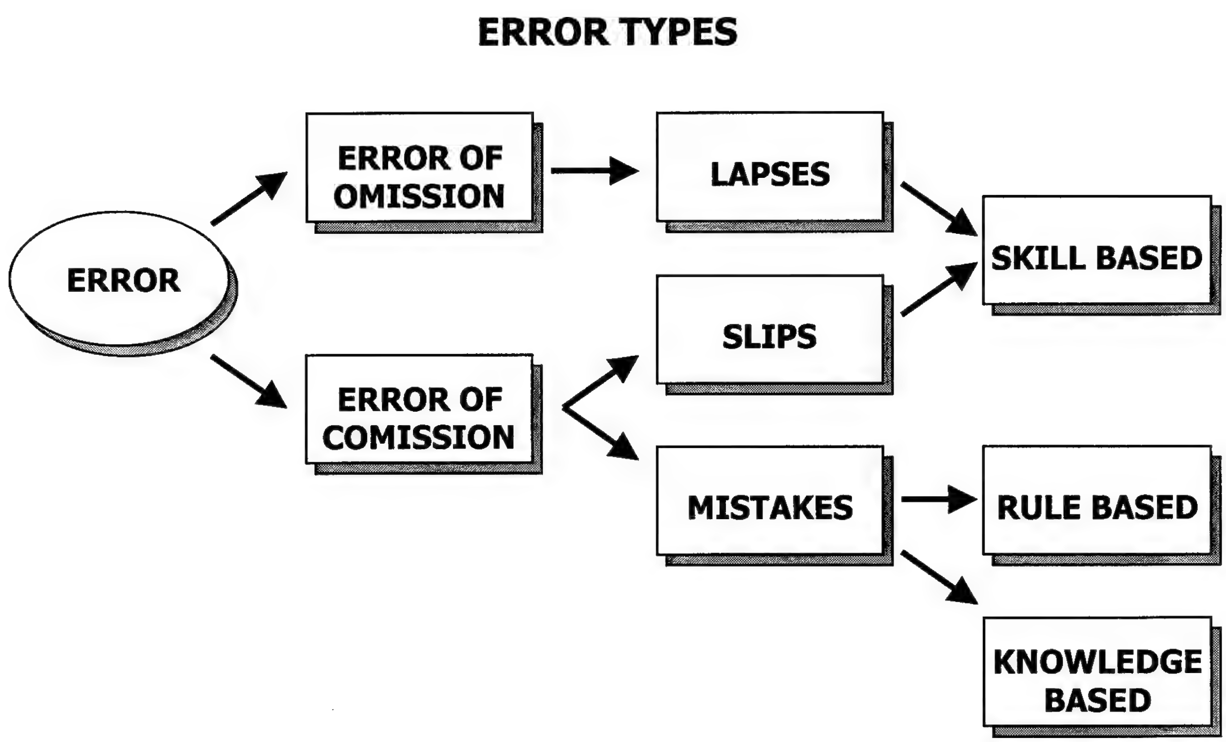

FIGURE 7: Sarter & Alexander Error Analysis Model

Wiegmann and Shappell (1996) use three different frameworks to analyze human error associated with U.S. Naval aviation accidents. These were a general information processing model (Wickens & Flach, 1988), a model of internal human malfunction (Rasmussen, 1982), and a model of unsafe acts (Reason, 1990). Results of their study revealed that all three frameworks allowed analysts to effectively categorize well over three-quarters of data from U.S. Navy and Marine corps aviation mishaps between that had occurred between 1977 and 1992. Similar to the studies done by O'Hare et al. (1994) and Sarter and Alexander (2000), these researchers found that the majority of accidents were associated with action or skill-based errors. Furthermore, like O'Hare et al., the results revealed that fatal accidents were more likely to be associated with decision and judgment errors (e.g. violations) than were non-fatal accidents. Wiegmann and Shappell (1996) suggested that these finding clearly indicated that the difference between a non-fatal and fatal-accident is not just one of luck. Rather, fatal accidents are due to a fundamentally different breakdown in the information and decision-making processes of pilots.

The results of the study by Wiegmann and Shappell (1996) also revealed some general deficiencies in the applications of the theoretical models they had employed. Specifically, they found that applied users of such system consider the terminology and theoretical labels within Reason's and Rasmussen's models to be somewhat confusing, and as a result inter-rater agreements concerning the classification of errors using these models was potentially compromised.

Therefore, they recommended removing such terms as "intended" and "unintended" actions from the model of unsafe acts. They also suggested that by combining the categories of rule- and knowledge-based mistakes into simply "decision errors" would make the system more user-friendly for investigators in the field. Finally, from their analysis, they discovered that certain perceptual errors that often occur in aviation (i.e., errors do to misjudging distance or altitude, visual illusions, or spatial disorientation) were not adequately captured within Reason's original model of unsafe acts. As a result they added this category of errors to the model. This revised taxonomy is presented in Figure 8.

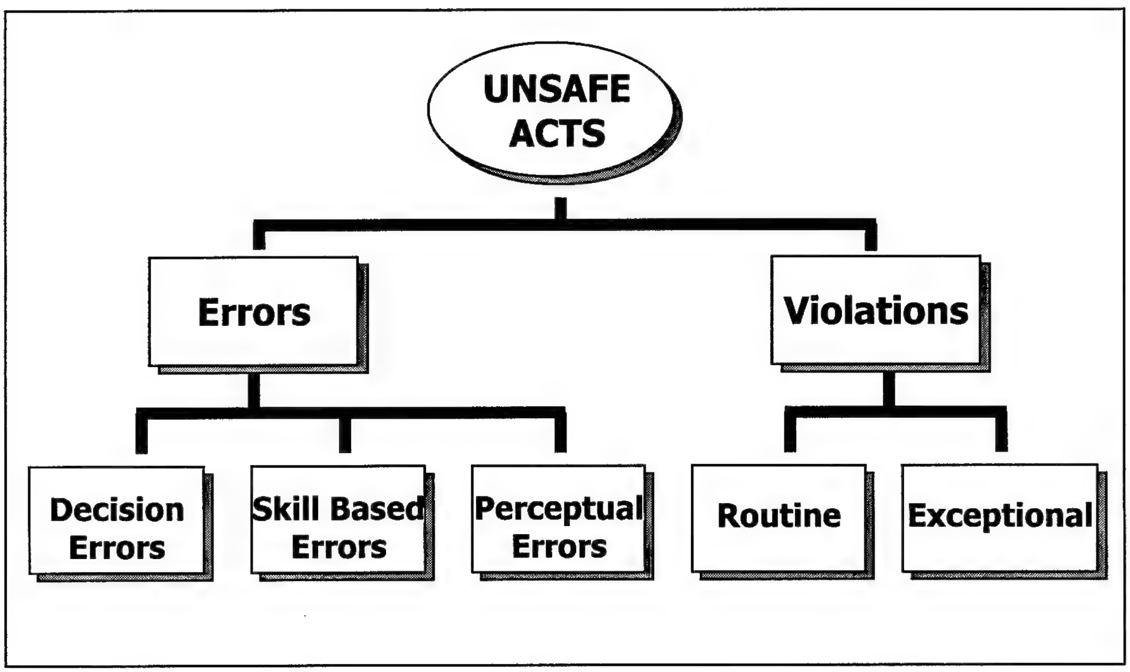

FIGURE 8: Revised Taxonomy of Unsafe Acts

Wiegmann and Shappell (2001b) used the revised taxonomy of unsafe acts to analyze 119 aircrew-related commercial aviation accidents that occurred in the U.S. between 1990 and 1996. These researchers utilized both a human factors expert and a commercially rated pilot to independently perform the coding process in order to determine the extent to which novices in human factors could use the system. Results revealed relatively good agreement levels between the two coders, with the commercial pilot and human factors expert concurring on the classification of errors approximately 76% of the time. Results also revealed findings consistent with previous studies. Specifically, skill-based errors constituted the largest percentage of errors associated with these accidents (60.5%). The next largest percentage involved decision errors (28.6%), violations (26.9%) and perceptual errors (14.3%). Also observed was general decline in the percentage of accidents associated with of skill-based errors over the years examined in the study. This finding was interpreted as reflecting improvements in aircraft automation that had occurred during this time period, particularly within the aircraft flown by smaller commercial air carriers. Also, observed however, was a slight increase in the percentage of accidents due to a violation of the rules, which revealed a tendency for pilots to "cut corner" due to organizational and economic pressures to achieve efficient and on-time operations.

In summary, the application of human error models to the design of frameworks for analyzing accident data has met with considerable success.

Studies using these frameworks to analyze both commercial and military aviation accidents have provided insights into the types of errors associated with these events. In general, these previous studies have all revealed that the largest proportions of the aviation accidents are associated with skill based errors. Such findings affirm the importance of attention and memory skills in the cockpit and suggest that across various types of aviation and pilot backgrounds (.e.g., experience levels and training) and other situational factors, the mismanagement of attention and memory processes is a major threat to aviation safety. Failures in decision making, while often associated with a smaller percentage of accidents than skill based errors, are more often associated with fatal accidents than non-fatal accidents; therefore reducing decision making errors in the cockpit may have the biggest impact on reducing fatal accident rates.

To date, however, a comprehensive human error analysis has yet to be conducted on GA accidents, even though these accidents account for the vast majority of aviation accidents and fatalities within the U.S. Perhaps the benefits delivered after applying theoretical frameworks of human error to accidents in other areas of aviation (i.e., commercial and military) could also be realized by applying such models to GA accident data.

Purpose of the Present Study

The purpose of this study is to analyze the nature and prevalence of different types of human causal-factors associated with general aviation accidents. Specifically, we use the revised taxonomy of unsafe operations

(Figure 8) to analyze the underlying nature and frequency of pilot errors associated with U.S. general aviation accidents that occurred over a nine-year period (1990 through 1998). Given the large number of GA accidents that occurred during this time period (slightly over 18,000), present research is directed to focus on a more manageable, yet highly important subset of these (n = 2,716), which are airplane (vs. helicopter, glider, or balloon) accidents involving fatalities (NTSB, 2003c). Furthermore, experienced GA pilots are utilized to perform the coding process to determine whether non-experts in human factors can reliably apply the error framework to the analysis of human error.

Previous analyses of aviation accident and incident data has demonstrated that skill based errors remain the most common form of error among commercial and military pilots. Given the basic task of flying an airplane (i.e., aviate, navigate, and communicate) are generally consistent across aviation domains (military, commercial, and GA), we expect that the largest percentage of GA accidents will also be associated with skill-based errors on the part of the pilot. Moreover, given GA pilots are generally younger and less experienced and typically receive less formalized training than military and commercial pilots, we further hypothesize that, in addition to being more prevalent than the other unsafe act categories, skilled-based errors are associated with an even larger absolute percentage of GA accidents than has been observed previously in the other aviation domains. It is important to note that accidents can have more

than one unsafe act cited as a cause or contributing factor, such that the sum of percentages each category

The data to be examined is comprised solely of fatal GA accidents. Therefore, decision errors will likely play a vital role in these events given previous studies have shown that a larger percentage of fatal accidents are often associated with decision errors than non-fatal accidents. In particular, we hypothesize that decision errors will be cited as the seminal error in the accident sequences more often than other types of unsafe acts; this is to say that decision errors will be coded as the first unsafe act, or the error that begins the chain of events, disproportionately compared to other types of unsafe acts within these fatal accident records.

Contrary to previous research, it is hypothesized that violations of the rules will arise more often as a causal factor in the GA accident data than has been previously reported within commercial or military flight operations. This difference is expected given the role of organizational structure, supervision, accountability, and retribution for adverse actions within the latter domains. Military and commercial aviation are highly regulated and monitored by relevant authorities governing such activities and pilots who break the rules or deviate from standard operating procedures are often caught and held culpable for such actions. However, considering that general aviation is much less structured and pervasive within the aviation arena, surveillance and enforcement of the rules and regulations is much more difficult and pilots are therefore less likely to get

caught. Consequently, violations may occur more often in GA and thus be associated with a larger percentage of accidents.

Finally, perceptual errors have historically been cited less frequently as an accident causal factor than other types of unsafe act. While research shows errors of perception to be more common in the military aviation domain due to the more dynamic nature of fighter aircraft maneuvers and operations, it is hypothesized that perceptual errors will be the least common cause of GA accidents. We also expect that the proportion of accidents associated with perceptual errors will more closely resemble those of commercial rather than military aviation.

CHAPTER 2

METHOD

Accident Database and Case Selection

General aviation accidents are investigated by experienced pilots who are trained investigators employed by the NTSB. These investigators collect and examine a variety of data surrounding the accident, including wreckage patterns, radar data, pilot records, weather reports, and witness interviews. Based on this information, investigators determine the probable cause of the accident and generate possible safety recommendations for preventing similar accidents. This information is summarized in a narrative report and the specific accident causal-factors are entered into a database using a set of standardized codes (e.g., breakdown in visual scan). The narrative report and data are submitted to NTSB headquarters in Washington, D.C., where they are checked for accuracy and subsequently endorsed as the official accident report. Both the NTSB and Federal Aviation Administration (FAA) then make this information available to the general public.

As part of a larger FAA study of the GA accident data, a comprehensive review of fatal accidents involving general aviation aircraft operating under Federal Aviation Regulations (FAR) Part 91, or non-commercial operations, between January 1990 and December 1998 was conducted using internet-database records maintained by the NTSB and the FAA. Of particular interest to this larger study are those accidents attributable, at least in part, to pilot error.

The analysis was also limited to fixed wing, general aviation airplanes and therefore excludes helicopters, gliders and experimental aircraft. Of these fatal airplane accidents, only those in which the investigation was completed, and the cause of the accident determined, were utilized in this study. A total of 2,426 accidents meet these criteria for further analysis. The narratives, descriptions, causal codes, and sequences of events presented within each of these accident reports were examined by trained staff and extracted for analysis by five GA pilots.

Again, we are only interested in those fatal accidents involving pilot error, not those accidents that are purely mechanical in nature or those with other (non-pilot) human involvement. This does not mean that mechanical failures or other factors such as weather do not exist in the present database, only that some form of pilot error was also involved in each of the accidents included in the final data.

Error Classification

Many of the accident cases identified for further analysis contained more than one human causal factor. Specifically, the 2,426 accidents examined in this study are associated with 6,066 pilot-errors. For each accident, these individual pilot-errors are classified by experienced pilots using the revised taxonomy of unsafe acts (Figure 8).

As part of the larger FAA project, five GA pilots were recruited from the Oklahoma City area as subject matter experts. All five were certified flight

instructors with a minimum of 1,000 flight hours in GA aircraft (mean = 3,530 flight hours). Each pilot received roughly 16 hours of training on human error theories and data classification procedures, presented by experts from the FAA's Civil Aeromedical Institute (CAMI). This training consisted of four hours of classroom instruction on human error models, including the revised taxonomy of unsafe acts. Definitions and examples of errors associated with each category within the revised framework were provided. An illustration of how to analyze accident reports and classify causal factors using the framework was also presented. Pilots then read 20 accident reports and practiced classifying the associated human casual factors as a group. It is worthwhile to note that coders were instructed that that only those causal factors identified by the NTSB were to be classified within the taxonomy. That is, the pilot-raters were instructed not to introduce additional casual factors that had not already been identified in the original investigation.

Each pilot was assigned 50 additional accident reports to analyze independently. They then returned and compared their results and discussed any disagreements concerning their error classifications. Feedback and coaching was provided on how to reach consensus when disagreements did occur. This process involved coders describing their rationale for the way they had classified a particular causal factor and justifying their decision based on the details contained in the narrative report of the accident.

After training, the five pilot-raters were randomly assigned accidents so at least two separate pilot-raters analyzed the human errors associated with each accident independently. Specifically, each pilot was assigned one-third of the accidents for a given year and randomly paired with a second pilot who coded the same set of accidents. Pilots then met to compare codes and when necessary discuss disagreements and achieve consensus. They were then assigned one-third of the accidents for a particular year and randomly paired with another pilot. This procedure continued until all the accidents had been coded. Pilot-coders were compensated for their time at an hourly rate.

During the coding process, data was collected and forwarded to the present researchers at the University of Illinois Institute of Aviation where it was reviewed. For quality assurance purposes, the original NTSB GA accident database was compared with incoming data from pilot coders to assure that their database exactly reflected NTSB data. The current researchers at the Institute of Avitaion performed all classifications beyond those supplied by the FAA (i.e., most frequent errors among unsafe act categories, error types, and environmental factor data) as well as all statistical analysis presented in the present study.

Inter-rater Reliability

Disagreements between pilot-coders were noted during the coding process. Overall, coders initially agreed on over 86% of the causal factor reclassifications and were able to reach consensus on the recoding of all of the

factors. To further examine the reliability of the Human Factors Analysis and Classification System (HFACS; Shappell & Wiegmann, 2001a), Cohen's kappa was calculated using coders' overall agreement rate (O'Hare et al., 1994). Kappa is a more stringent index of inter-rater reliability in that it accounts for the probability of coders agreeing simply by chance on the classification of any given causal factor. Fleiss (1981) has characterized values of kappa over 0.75 as "excellent" and values between 0.6 and 0.75 as "good." The value of kappa obtained in this study is 0.80, which generally reflects an "excellent" level of agreement according to these conventional standards.

CHAPTER 3

RESULTS

The results of the data analysis will be presented in three stages. First, the percentage of accidents associated with each unsafe act will be described, including a description of trends of unsafe act accidents and seminal unsafe acts over the nine years examined in the study. Next, associations among the unsafe act categories will be addressed by reporting the correlations among these causal factors. Finally, the influence of environmental variables such as weather and mechanical malfunctions are examined and the relationships between the environmental variables and the unsafe act categories will be presented.

Error Analysis

Skill based errors. Figure 9 presents the percentages of accidents associated with each unsafe act category. Note that the accidents could have more than one causal factor, and therefore percentages of accidents do not total 100%. Additionally, each accident may be associated with multiple instances of the same type of unsafe act (e.g., several skill based errors), however the percentages presented here are for those accidents that involve at least one instance of a particular unsafe act category.

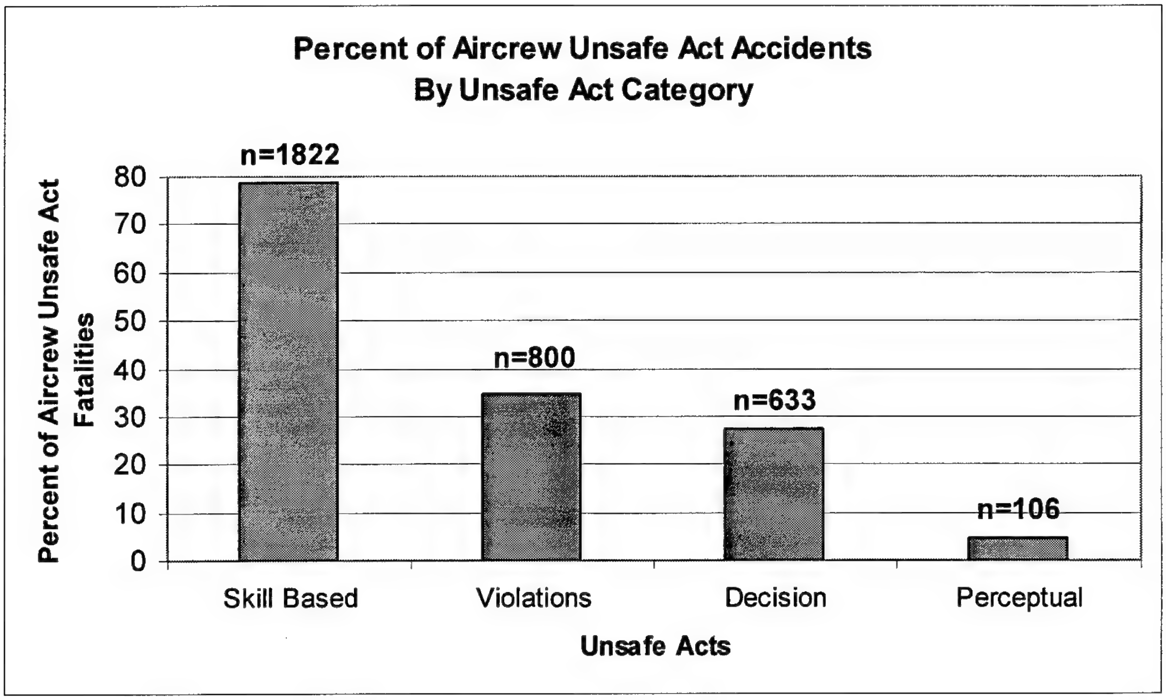

Figure 9: Percent of aircrew unsafe act accidents by unsafe act category.

As predicted on the basis of previous classification studies of military and commercial flight, the largest percentage of accidents is associated with skill based errors. Approximately 79% (n=1,822) of all aircrew-error related accidents cite at least one skill based error as a cause or contributing factor. As hypothesized, this proportion is higher than those previously observed for military and commercial pilot data (75.8% [Sarter & Alexander, 2000], 60% [Wiegmann & Shappell, 2001a], 45% [Shappell & Wiegmann, 2001b]). Analysis of the data on a year-by-year basis reveals that the proportion of accidents associated with at least one skill based error remains relatively unchanged over the 9-year period examined in the study (Figure 10), with the highest proportion

at 86.2% in 1994 and lowest in 1992 at 74.9%. A trend analysis using Daniels Test for non-parametric data (Conover, 1999) reveals no statistically significant relationship or change in the proportions of accidents associated with skill based errors across the years examined in this study (r=.433, p=.244).

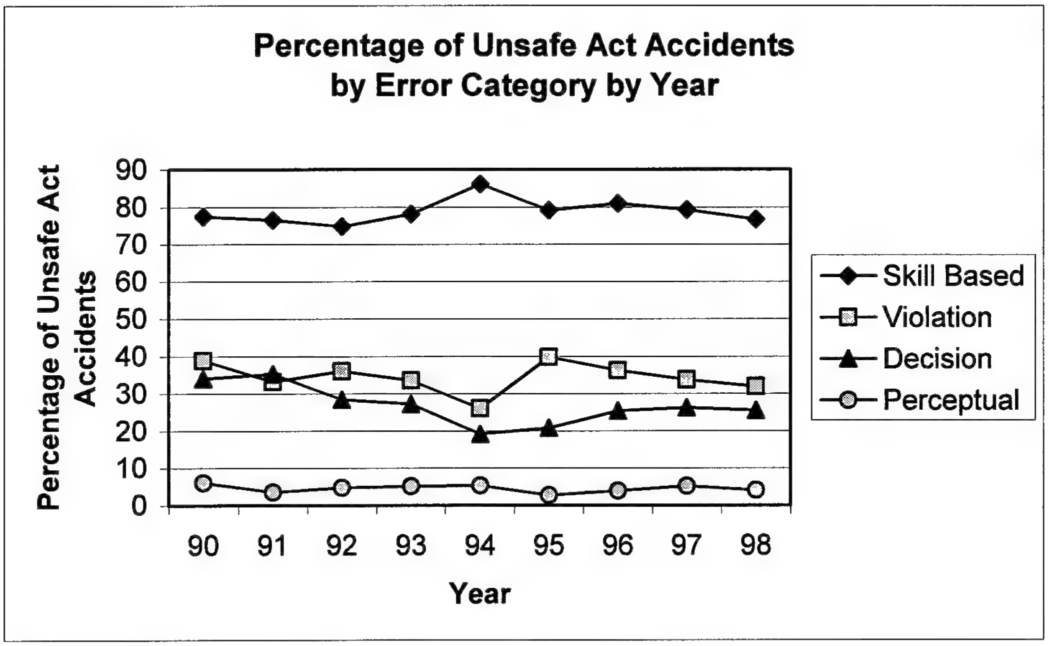

Figure 10: Percentage of unsafe act accidents by error category by year.

Appendix A provides an exhaustive list of all of the NTSB database causal factors considered by the subject matter experts (i.e. pilot coders) to reflect skill based errors (n=310). These descriptions were grouped according to their similar nature, often concerning subtle semantic differences (e.g. altitude inaccurate, altitude inadequate, and altitude improper) or by their similar behavioral nature (e.g. low altitude flight maneuver attempted and buzzing

performed). Table 1 presents the ten most frequently occurring categories as within all skill based errors (n=2,678), and Appendix B lists the compositions of each.

Table 1: Ten Most Frequent Skill Based Error Categories

Error Category	Frequency	Percent
Airspeed Not Maintained	513	19.2%
Aircraft Control/Handling	410	15.3%
Stall/Spin	391	14.6%
Altitude Improper/Not Maintained	341	12.7%
Clearance (from Object or Aircraft) Not Maintained	189	7.1%
Visual Look Out Inadequate	157	5.9%
Fuel Mismanagement	61	2.3%
VFR Flight Into IMC	58	2.2%
Emergency Procedure Error	28	1.0%
Proper Glide Path Not Maintained	22	0.8%

An examination of Table 1 indicates that nearly 20% of skill based errors involve errors in maintaining airspeed, followed closely by the lack of aircraft control (15.3%), the occurrence of a stall or spin (14.6%), and errors in maintaining proper altitude (12.7%). Beyond these four categories the proportions begin to diminish, as such errors as inadequate clearance or visual lookout, fuel mismanagement, and all others account for a total of less than 20% of all skill based errors.

An attempt was made to perform a deeper analysis of skill based errors to determine if they could be categorized into more traditional categories. However, given the subtle, superficial differences in nomenclature used by

accident investigators and coding officials, this sort of analysis was difficult. Present research findings can attribute at least 15% of skill based errors to attention slips or memory lapses. These are errors clearly involving a breakdown in attention and memory processes such as an inadequate visual look out, fuel mismanagement, or emergency procedure errors. Due to the nomenclature used to describe skill based errors, it is impossible to determine the extent to which attention and memory failures contribute the remaining skill based errors that at their surface appear to be physical "stick and rudder" skills.

For example, the skill based error categories of "airspeed not maintained" and "aircraft control/handling" could, by their surface descriptions, be considered physical coordination failures dealing with aircraft control. It is important to consider, however, that these apparent control failures could have been caused by the pilot's failure to monitor flight variables or due to a breakdown of attention in a high workload situation, and would therefore be categorized as skill based errors due to attention or memory failure.

Seminal events are defined as the first error cited within the sequence of events in an accident. Fully 88% of accidents that cite an unsafe act as a cause or factor in the accident begin with an unsafe act as the seminal event. Among accidents citing an unsafe act as the seminal event (n=2,036), nearly 55% (n=1,111) begin with a skill based error. The five most frequently occurring categories of seminal skill based errors are presented in Table 2 and are expanded upon in Appendix C.

Table 2: Five Most Frequent Seminal Skill Based Error Categories

Seminal Error Category	Frequency	Percent
Airspeed Not Maintained	**253**	**22.8%**
Aircraft Control/Handling	**182**	**16.4%**
Altitude Improper/Not Maintained	**123**	**11.1%**
Clearance (from Object of Aircraft) Not Maintained	**103**	**9.3%**
Visual Look Out Inadequate	**70**	**6.3%**

The types and frequencies of skill based errors coded as seminal events closely reflect the categories that are cited most frequently overall (Table 1), stall or spin occurrence notwithstanding.

Figure 11 presents the percentages of accidents that begin with seminal errors from each error category presented by year. Unlike in some figures, the presented percentages total 100% each year as there is only one seminal event for each accident and no overlapping of unsafe act categories occurs. A trend analysis was also performed to determine if trends exist within unsafe act seminal event data from year to year. Results reveal a non significant trend, with the percentage of accidents that involve skill based errors as the seminal unsafe act increasing slightly when viewed from year to year ($r=.500$, $p=.170$).

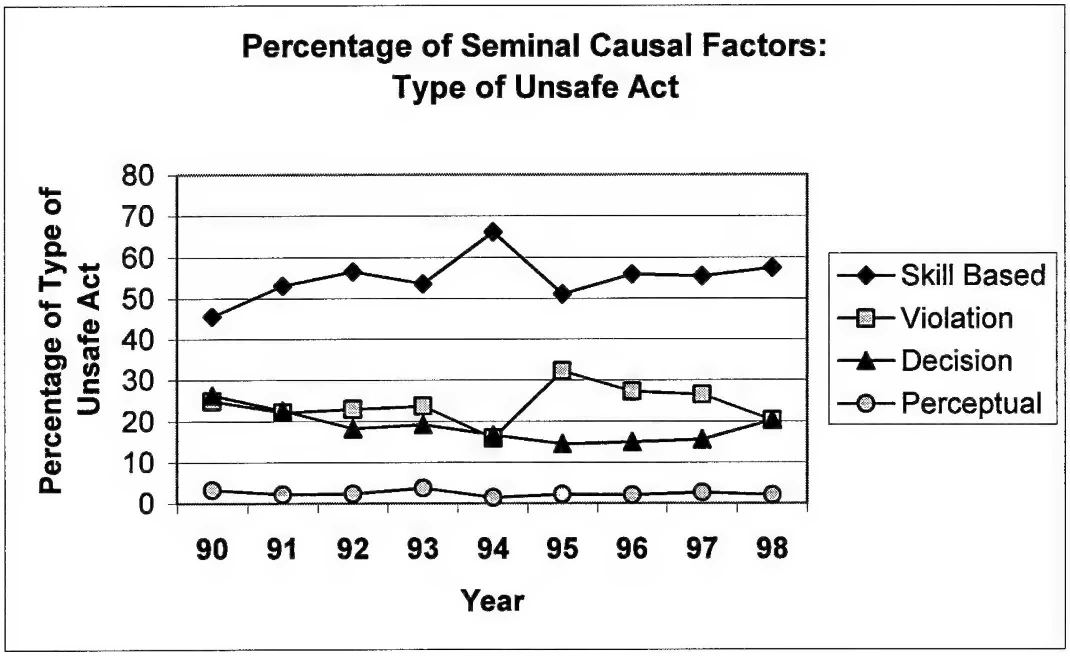

Figure 11: Percentage of seminal causal factors by error category by year

Violations. As illustrated in Figure 9, accidents associated with violations of rules or regulations constitute the next highest proportion within the database, with roughly 35% of the accidents examined (n=800) involving at least one violation by aircrew. This finding also confirms our hypothesis of the frequency of violations within GA accident data to be higher than in military and commercial aviation (30% [Shappell & Wiegmann, 2001b], 27%[Wiegmann & Shappell, 2001a]). A trend analysis indicates that the proportion of accidents associated with at least one violation remains relatively constant over the 9-year period examined (r=-.183, p=.637), with the highest proportion at nearly 40% in 1995 and lowest in 1994 at 26.1% (Figure 10).

Appendix D provides a list of all causal factor descriptions coded as violations (n=125). From these, the ten categories of most frequently occurring violations are derived and presented in Table 3 as percentages within all violations cited (n=945). A detailed breakdown of the components of each violation category is presented in Appendix E.

Analysis of the fundamental types of unsafe acts that are included within the violations categories reveals that over half (51.4%) are weather related violations of visual flight rules (VFR) flight into instrument meteorological conditions (IMC), flight into adverse weather, and improper IFR procedures. The remaining seven violation categories, including exceeding aircraft design stress limits (9.6%), improper aircraft weight and balance (5.2%), low altitude flight or buzzing performed (4.9%), and the performance of aerobatics (3.2%), make up the remaining 48.6% of all cited violations.

Table 3: Ten Most Frequent Violation Categories

Violation Category	Frequency	Percent
VFR Flight Into IMC	269	28.5%
Flight Into Adverse Weather	162	17.1%
Design Stress Limits of Aircraft Exceeded	91	9.6%
IFR Procedure Not Followed	55	5.8%
Aircraft Weight/Balance	49	5.2%
Procedures/Directives Not Followed	47	5.0%
Low Altitude Flight/Buzzing Performed	46	4.9%
Operation With Known Deficiency in Equipment	42	4.4%
Aerobatics Performed	30	3.2%
Minimum Descent Altitude Not Maintained	28	3.0%

Of accidents that cite an unsafe act as the seminal event, 24% (n=488) begin with a violation. The five most frequently occurring categories of seminal violations are presented in Table 4 and are elaborated upon in Appendix F. As with skill based errors, these categories parallel factors previously outlined, such as VFR flight into IMC, flight into adverse weather, instrument procedures not followed, and others. Additionally, no statistically significant trend in the percentage of accidents having violations as seminal unsafe acts by year (Figure 11) is evident (r=.133, p=.732).

Table 4: Five Most Frequent Seminal Violation Categories

Seminal Violation Category	Frequency	Percent
VFR Flight Into IMC	**166**	**34.0%**
Flight Into Adverse Weather	**97**	**19.9%**
IFR Procedure Not Followed	**44**	**9.0%**
Low Altitude Flight/Buzzing Performed	**30**	**6.1%**
Operation With Known Deficiency in Equipment	**28**	**5.7%**

Decision errors. When compared to the other unsafe act categories, decision error trends are found to be similar to those revealed for violations, as accidents attributable at least in part to decision errors on the part of the aircrew are associated with 27.4% (n=633) of the accidents examined (Figure 9). As hypothesized, this proportion parallels that reported by Wiegmann & Shappell (29%) in one recent study (2001a) but is much lower than those found within commercial and military aviation in other recent studies (50% [Shappell & Wiegmann, 2001b], 35% [O'Hare et al., 1994]). When comparing the relative

percentages by year (Figure 9) the difference between the highest (35.3% in 1991) and the lowest (19.2% in 1994) proportions is slightly greater than that of other error categories, contributing toward the significant downward trend in decision errors within the data studied (r=-.667, p=.050).

Subject matter experts classified 198 different NTSB causal factors as examples of decision errors (Appendix G) a total of 733 times, and a detailed breakdown of the components of each of the most frequent decision error categories is shown in Appendix H. Table 5 presents these categories.

Table 5: Ten Most Frequent Decision Error Categories

Error Category	Frequency	Percent
Inflight Planning Improper	187	25.5%
Altitude/Clearance Improper	70	9.5%
Judgment Poor	49	6.7%
Aborted Take Off or Landing	35	4.8%
Weather Evaluation Inadequate	31	4.2%
Planning Decision Error	29	4.0%
Refueling Error	21	2.9%
Low Altitude Flight/Maneuver	20	2.7%
Preflight Briefing Service Not Obtained/Followed	20	2.7%
Remedial Action Improper	17	2.3%

Within the ten most frequent decision error categories, a much larger spectrum of error types is presented as compared with skill based errors and violations. Among these error categories very little overlap is found, as each represents a conceptually or behaviorally different form of decision error. Improper inflight planning tops the list, contributing to over a quarter (25.5%) of

all decision errors. Errors categorized as inflight planning refer to planning or plan revision performed after the aircraft has taken off, and are often studied as plan continuation errors (Orasanu, 1993; Burian, Orasanu, & Hitt, 2000; Wiegmann, Goh, & O'Hare, 2002; Muthard & Wickens, 2003). The remaining decision errors, such as improper altitude selection (9.5%), poor judgment (6.7%), inadequate weather evaluation (4.2%), and preflight planning decision errors (4.0%), each occur at relatively similar frequencies.

Further analysis was performed to determine the extent to which decision errors are coded in the database as incorrect decisions (e.g., poor, inadequate) versus untimely decisions (delayed). Incorrect decisions account for 86.0% of decision errors, whereas delayed decisions make up only slightly more than 7% (Figure 12)

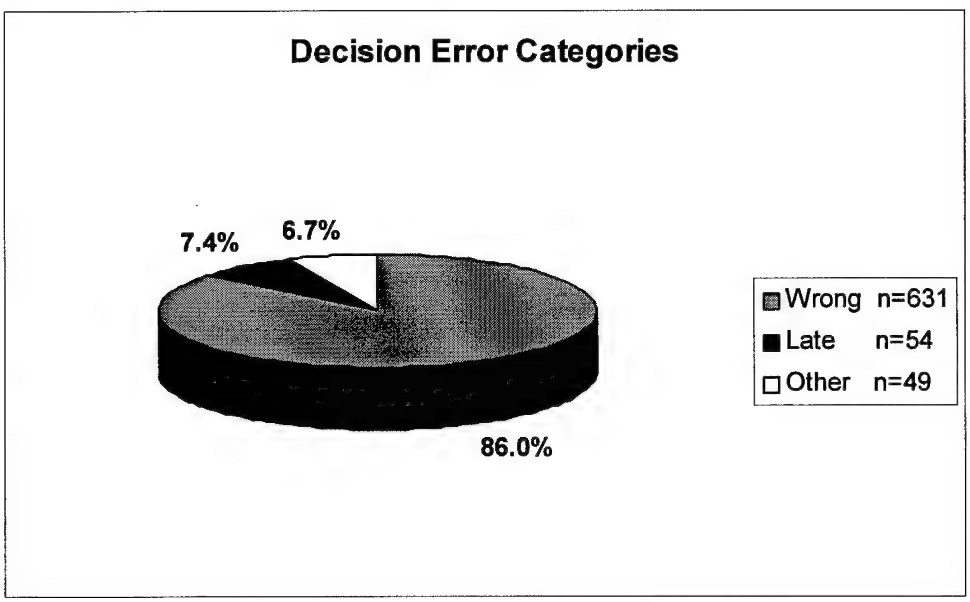

Figure 12: Decision error categories.

Contrary to our stated hypothesis, within accidents involving an unsafe act as the seminal event, only 19% (n=387) cite an error in decision making as the first unsafe act. This proportion is slightly lower than that of seminal violations (24%) and much less than that of seminal skill based errors (55%). The five most frequently occurring categories of seminal decision errors are presented in Table 6 and are expanded upon in Appendix I. As before, the composition and frequencies of seminal decision error categories are very similar to those describing all occurrences of decision error (Table 5), revealing improper inflight planning as the most common seminal decision error (24.0%).

Table 6: Five Most Frequent Seminal Decision Error Categories

Seminal Error Category	Frequency	Percent
Inflight Planning Improper	93	24.0%
Judgment Poor	35	9.0%
Planning Decision Error	26	6.7%
Altitude/Clearance Improper	21	5.4%
Weather Evaluation Inadequate	19	4.9%

Analysis of the frequency of seminal decision errors over time also yields results similar to those for all decision errors by year, revealing the highest level of significance (albeit not significant) among all seminal unsafe act categories ($r=-.567$, $p=.112$) again indicating the downward trend of seminal decision errors by year (Figure 10).

Perceptual errors. As hypothesized, the present research also finds that the proportion of accidents associated with perceptual errors is relatively low as compared with commercial and military aviation (20% [Shappell & Wiegmann, 2001b], 14% [Wiegmann & Shappell, 2001a]) and compared to skill based errors, violations, and decision errors. In fact, only 4.6% (n=106) of the accidents reviewed involve any form of perceptual error as coded by investigators (Figure 9). Due in large part to their low prevalence, virtually no difference is evident between proportions of perceptual error by year, precluding further comparisons across calendar years (Figure 10).

Review of accident causes and factors coded as perceptual errors (n=33, see Appendix J) reveals that nearly half (47.4%) of all errors of perception (n=114) involve misjudging information (distance or descent, altitude, maneuver or procedure, low altitude flight maneuver, wind readings, or weather information) that is present as opposed to information that is not detected. Table 7 presents the categories of most frequent perceptual errors as percentages within all perceptual errors cited (n=114).

Table 7: Ten Most Frequent Perceptual Error Categories

Error Category	Frequency	Percent
Visual/Aural Detection/Perception	34	29.8%
Distance/Descent Misjudged	20	17.5%
Altitude Misjudged	18	15.8%
Clearance (from Object or Aircraft) Not Maintained	18	15.8%
Maneuver/Procedure Misjudged	12	10.5%
Spatial Disorientation	5	4.4%
Low Altitude Flight Maneuver Misjudged	2	1.8%
Wind/Weather Information Misjudged	2	1.8%
Judgment Poor	1	0.9%
VFR into IMC Inadvertent	1	0.9%

It is not possible using the current NTSB data to determine what percentage of the most frequently cited category of perceptual errors (visual or aural detection or perception) involve misperception as compared to nonperception. Other categories of perceptual error cited in the database include improper clearance (15.8%) and spatial disorientation (4.4%). A detailed breakdown of the components of each error category is presented in Appendix K.

Within the accidents citing an unsafe act as the seminal event, only 2.4% (n=50) begin with a perceptual error but nearly half (47.2%) of all accidents associated with perceptual errors identify a perceptual error as the seminal event. Seminal perceptual errors show no trend (r=-.452, p=.222) over the nine-year period of study (Figure 11). The four most frequently occurring categories of seminal perceptual errors are presented in Table 8 and are expanded upon in Appendix L.

Table 8: Four Most Frequent Seminal Perceptual Error Categories

Seminal Error Category	Frequency	Percent
Distance/Descent Misjudged	16	32.0%
Clearance (from Object or Aircraft) Not Maintained	13	26.0%
Maneuver Misjudged	11	22.0%
Altitude Misjudged	8	16.0%

The composition and frequencies among all coded perceptual errors (Table 7) are preserved and reflected in seminal perceptual error category data with the exception of the nondescript category of visual/aural detection/perception. Misjudgment of distance or descent occurs with the highest frequency at 32.0% and is followed by errors in maintaining clearance (26.0%), misjudged maneuvers (22.0%), and misjudged altitude (16.0%).

Associations Among Unsafe Acts

Calculating levels of association among unsafe act categories shows whether two categories are more or less likely to be represented within the same accident than would be predicted on the basis of the independent probabilities of their frequencies of occurrence. This relationship can be revealed by the Chi-Square statistic of association, which will be discussed further in the following section of this paper. A number of pairs of unsafe act categories yield significant associations, but none more consistently than skill based errors.

Skill based errors are found to have statistically significant negative associations with each of the other unsafe act categories. This means that a skill

based error is less likely to occur in an accident citing any other unsafe act. Table 9 plots the number of accidents that contain each of the four combinations of error category (where "1" represents the category as present in the accident) The negative association to violations (X^2 (1, n=2426) = 197.803, p<.001) is due chiefly to the large proportion of skill based error accidents that occur in the absence of a violation (74.4%) even though over 57% of all accidents involving violations also cite a skill based error.

Table 9: Association of skill based errors and violations

			Violations (Unsafe Acts)		
			0	1	Total
Skill-Based Errors (Unsafe Acts - Errors)	0	Count	264	340	604
		Expected Count	404.8	199.2	604.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	43.7%	56.3%	100.0%
		% within Violations (Unsafe Acts)	16.2%	42.5%	24.9%
	1	Count	1362	460	1822
		Expected Count	1221.2	600.8	1822.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	74.8%	25.2%	100.0%
		% within Violations (Unsafe Acts)	83.8%	57.5%	75.1%
Total		Count	1626	800	2426
		Expected Count	1626.0	800.0	2426.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	67.0%	33.0%	100.0%
		% within Violations (Unsafe Acts)	100.0%	100.0%	100.0%

The negative association between decision errors and skill based errors (X^2 (1, n=2426) = 41.707, p<.001) also indicates the lower likelihood of a decision error to be coded within the same accident as a skill based error (Table 10). While 34.4% of decision error accidents do not include a skill based error

among causal factors, an even smaller percentage codes both within the same accident (22.8% of all skill based error related accidents).

Table 10: Association of skill based errors and decision errors

			Decision Errors (Unsafe Acts - Errors)		
			0	1	Total
Skill-Based Errors (Unsafe Acts - Errors)	0	Count	386	218	604
		Expected Count	446.4	157.6	604.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	63.9%	36.1%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	21.5%	34.4%	24.9%
	1	Count	1407	415	1822
		Expected Count	1346.6	475.4	1822.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	77.2%	22.8%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	78.5%	65.6%	75.1%
Total		Count	1793	633	2426
		Expected Count	1793.0	633.0	2426.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	73.9%	26.1%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

As shown in Table 11, errors of perception are also found to have strong negative associations with skill based errors (X^2 (1, n=2426) = 40.216, p<.001). Nearly half (49.1%) of all accidents involving perceptual errors also involve a skill based error, but given that such a large number of accidents cite skill based error (over 75%), a negative association is revealed. Specifically, a slight majority of perceptual error accidents do not include a skill based error (50.9%) whereas the vast majority of skill based error accidents do not involve a perceptual error (97.1%).

Table 11: Association of skill based errors and perceptual errors

			Perceptual Errors (Unsafe Acts - Errors) 0	1	Total
Skill-Based Errors (Unsafe Acts - Errors)	0	Count	550	54	604
		Expected Count	577.6	26.4	604.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	91.1%	8.9%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	23.7%	50.9%	24.9%
	1	Count	1770	52	1822
		Expected Count	1742.4	79.6	1822.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	97.1%	2.9%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	76.3%	49.1%	75.1%
Total		Count	2320	106	2426
		Expected Count	2320.0	106.0	2426.0
		% within Skill-Based Errors (Unsafe Acts - Errors)	95.6%	4.4%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

Correspondingly, a perceptual error is also less likely to be coded within the same accident as a violation (Table 12).

Table 12: Association of perceptual errors and violations

			Violations (Unsafe Acts) 0	1	Total
Perceptual Errors (Unsafe Acts - Errors)	0	Count	1536	784	2320
		Expected Count	1555.0	765.0	2320.0
		% within Perceptual Errors (Unsafe Acts - Errors)	66.2%	33.8%	100.0%
		% within Violations (Unsafe Acts)	94.5%	98.0%	95.6%
	1	Count	90	16	106
		Expected Count	71.0	35.0	106.0
		% within Perceptual Errors (Unsafe Acts - Errors)	84.9%	15.1%	100.0%
		% within Violations (Unsafe Acts)	5.5%	2.0%	4.4%
Total		Count	1626	800	2426
		Expected Count	1626.0	800.0	2426.0
		% within Perceptual Errors (Unsafe Acts - Errors)	67.0%	33.0%	100.0%
		% within Violations (Unsafe Acts)	100.0%	100.0%	100.0%

Nearly 85% of perceptual error accidents do not involve a violation; likewise, 98.0% of violation related accidents do not involve a perceptual error (X^2 (1, n=2426) = 16.036, p<.001).

The association between perceptual error accidents and those involving decision errors, however, is not found to be significant (X^2 (1, n=2426) = .281, p=.596) as decision errors occur within approximately the same proportion of accidents involving a perceptual error (28.3%) as accidents that do not involve a perceptual error (26.0%) as revealed in Table 13.

Table 13: Association of perceptual errors and decision errors

			Perceptual Errors (Unsafe Acts - Errors)		
			0	1	Total
Decision Errors (Unsafe Acts - Errors)	0	Count	1717	76	1793
		Expected Count	1714.7	78.3	1793.0
		% within Decision Errors (Unsafe Acts - Errors)	95.8%	4.2%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	74.0%	71.7%	73.9%
	1	Count	603	30	633
		Expected Count	605.3	27.7	633.0
		% within Decision Errors (Unsafe Acts - Errors)	95.3%	4.7%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	26.0%	28.3%	26.1%
Total		Count	2320	106	2426
		Expected Count	2320.0	106.0	2426.0
		% within Decision Errors (Unsafe Acts - Errors)	95.6%	4.4%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

Finally, no statistically significant association is found between decision errors and violations (X^2 (1, n=2426) = .176, p=.675; see Table 14) The proportion of accidents that do not involve a violation and the proportion of

accidents that do involve a violation are nearly equal among decision error related accidents (25.8% and 26.6%, respectively).

Table 14: Association of decision errors and violations

			Violations (Unsafe Acts)		
			0	1	Total
Decision Errors (Unsafe Acts - Errors)	0	Count	1206	587	1793
		Expected Count	1201.7	591.3	1793.0
		% within Decision Errors (Unsafe Acts - Errors)	67.3%	32.7%	100.0%
		% within Violations (Unsafe Acts)	74.2%	73.4%	73.9%
	1	Count	420	213	633
		Expected Count	424.3	208.7	633.0
		% within Decision Errors (Unsafe Acts - Errors)	66.4%	33.6%	100.0%
		% within Violations (Unsafe Acts)	25.8%	26.6%	26.1%
Total		Count	1626	800	2426
		Expected Count	1626.0	800.0	2426.0
		% within Decision Errors (Unsafe Acts - Errors)	67.0%	33.0%	100.0%
		% within Violations (Unsafe Acts)	100.0%	100.0%	100.0%

Associations Between Unsafe Acts and Environmental Factors

Additional analyses were also performed to determine the relationships, if any, between mechanical and environmental factors cited as causes or contributing to the accidents involving unsafe acts by pilots.

The two broad classifications of environmental factors represented in the accident database are maintenance or mechanical malfunctions and weather conditions. Maintenance and mechanical malfunctions include those causes or factors which involve structural component failures, engine malfunctions, and improper maintenance of the aircraft (tasks performed incorrectly or not at all) that leads to a mechanical malfunction. Within the category of weather, many

specific conditions are cited as causal factors to accidents, including fog, clouds, surface winds, winds aloft, rain, obscuration, haze, and icing conditions.

Maintenance and mechanical factors. Within the present study, relatively few accidents (n=193, 8.0%) cite mechanical or maintenance failures as causes or contribution factors in the accident. Maintenance or mechanical factors are not found to have an association with either skill based errors (Table 15) or perceptual errors (Table 16). The percentage of skill based errors cited in the presence of mechanical factors (74.1%) is equal to the likelihood of citation in their absence (75.2%), so their association is not found to be statistically significant (X^2 (1, n=2426) = .114, p=.735). Correspondingly, perceptual errors are not significantly associated with mechanical or maintenance failures (X^2 (1, n=2426) = .025, p=.874) and also reflect the equal proportions of perceptual errors in the presence (4.1%) or in the absence (4.4%) of these conditions.

Table 15: Association of mechanical factors and skill based errors

			Skill-Based Errors (Unsafe Acts - Errors)		
			0	1	Total
C/F Maint/Mech	0	Count	554	1679	2233
		Expected Count	555.9	1677.1	2233.0
		% within C/F Maint/Mech	24.8%	75.2%	100.0%
		% within Skill-Based Errors (Unsafe Acts - Errors)	91.7%	92.2%	92.0%
	1	Count	50	143	193
		Expected Count	48.1	144.9	193.0
		% within C/F Maint/Mech	25.9%	74.1%	100.0%
		% within Skill-Based Errors (Unsafe Acts - Errors)	8.3%	7.8%	8.0%
Total		Count	604	1822	2426
		Expected Count	604.0	1822.0	2426.0
		% within C/F Maint/Mech	24.9%	75.1%	100.0%
		% within Skill-Based Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

Table 16: Association of mechanical factors and perceptual errors

			Perceptual Errors (Unsafe Acts - Errors) 0	1	Total
C/F Maint/Mech	0	Count	2135	98	2233
		Expected Count	2135.4	97.6	2233.0
		% within C/F Maint/Mech	95.6%	4.4%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	92.0%	92.5%	92.0%
	1	Count	185	8	193
		Expected Count	184.6	8.4	193.0
		% within C/F Maint/Mech	95.9%	4.1%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	8.0%	7.5%	8.0%
Total		Count	2320	106	2426
		Expected Count	2320.0	106.0	2426.0
		% within C/F Maint/Mech	95.6%	4.4%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

The unsafe act categories of decision errors and violations are both found to have a negative association with maintenance and mechanical failures. The relatively strong association to decision errors (X^2 (1, n=2426) = 4.458, p=.035; see Table 17) is concluded to be negative by the difference in the percentage of decision error accidents that occur in the absence of mechanical or maintenance failures (94.0%) versus in their presence (6.0%). Violations follow suit (Table 18) in that the difference between the proportions of citations in the presence (4.6%) and in the absence (95.4%) of these factors is substantial, and this difference is represented in the high level of significance of the strong negative association between these categories (X^2 (1, n=2426) = 18.080, p<.001).

Table 17: Association of mechanical factors and decision errors

			Decision Errors (Unsafe Acts - Errors)		
			0	1	Total
C/F Maint/Mech	0	Count	1638	595	2233
		Expected Count	1650.4	582.6	2233.0
		% within C/F Maint/Mech	73.4%	26.6%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	91.4%	94.0%	92.0%
	1	Count	155	38	193
		Expected Count	142.6	50.4	193.0
		% within C/F Maint/Mech	80.3%	19.7%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	8.6%	6.0%	8.0%
Total		Count	1793	633	2426
		Expected Count	1793.0	633.0	2426.0
		% within C/F Maint/Mech	73.9%	26.1%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

Table 18: Association of mechanical factors and violations

			Violations (Unsafe Acts)		
			0	1	Total
C/F Maint/Mech	0	Count	1470	763	2233
		Expected Count	1496.6	736.4	2233.0
		% within C/F Maint/Mech	65.8%	34.2%	100.0%
		% within Violations (Unsafe Acts)	90.4%	95.4%	92.0%
	1	Count	156	37	193
		Expected Count	129.4	63.6	193.0
		% within C/F Maint/Mech	80.8%	19.2%	100.0%
		% within Violations (Unsafe Acts)	9.6%	4.6%	8.0%
Total		Count	1626	800	2426
		Expected Count	1626.0	800.0	2426.0
		% within C/F Maint/Mech	67.0%	33.0%	100.0%
		% within Violations (Unsafe Acts)	100.0%	100.0%	100.0%

Weather conditions. Weather conditions contribute to a large number of the accidents studied here (n=835, 34.4%). The relationships between the unsafe act categories and weather related causal factors also provide an indication of trends present in the accident data.

Violations are revealed to represent the only positive association in the current study (Table 19). The strong association of accidents involving violations to weather factors (X^2 (1, n=2426) = 40.216, p<.001) indicates that violations are much more frequently cited among accidents involving weather (57.5%) than in accidents that do not designate weather as a contributing factor to the accident (42.5%). This association may reflect the coders' distinct choice to assign VFR flight into IMC into the violation category rather than, for example, the decision error category.

Table 19: Association of weather factors and violations

			Violations (Unsafe Acts)		
			0	1	Total
C/F Weather	0	Count	1251	340	1591
		Expected Count	1066.4	524.6	1591.0
		% within C/F Weather	78.6%	21.4%	100.0%
		% within Violations (Unsafe Acts)	76.9%	42.5%	65.6%
	1	Count	375	460	835
		Expected Count	559.6	275.4	835.0
		% within C/F Weather	44.9%	55.1%	100.0%
		% within Violations (Unsafe Acts)	23.1%	57.5%	34.4%
Total		Count	1626	800	2426
		Expected Count	1626.0	800.0	2426.0
		% within C/F Weather	67.0%	33.0%	100.0%
		% within Violations (Unsafe Acts)	100.0%	100.0%	100.0%

Decision errors are not found to have a significant relationship with accidents involving weather (X^2 (1, n=2426) = .789, p=.374; see Table 20), as decision errors are equally likely to occur in accidents involving weather (27.2%) and accidents not involving weather (25.5%). Conversely, perceptual and skill based errors both show a strong negative association to weather factors.

Table 20: Association of weather factors and decision errors

			Decision Errors (Unsafe Acts - Errors)		
			0	1	Total
C/F Weather	0	Count	1185	406	1591
		Expected Count	1175.9	415.1	1591.0
		% within C/F Weather	74.5%	25.5%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	66.1%	64.1%	65.6%
	1	Count	608	227	835
		Expected Count	617.1	217.9	835.0
		% within C/F Weather	72.8%	27.2%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	33.9%	35.9%	34.4%
Total		Count	1793	633	2426
		Expected Count	1793.0	633.0	2426.0
		% within C/F Weather	73.9%	26.1%	100.0%
		% within Decision Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

The negative association of perceptual error accidents to weather related accidents (Table 21) is significant (X^2 (1, n=2426) = 7.946, p=.005). Accidents are much more likely to involve a perceptual error when weather is not considered a causal factor (78.3% of perceptual error accidents) than when weather does contribute to the accident (21.7%).

Table 21: Association of weather factors and perceptual errors

			Perceptual Errors (Unsafe Acts - Errors)		
			0	1	Total
C/F Weather	0	Count	1508	83	1591
		Expected Count	1521.5	69.5	1591.0
		% within C/F Weather	94.8%	5.2%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	65.0%	78.3%	65.6%
	1	Count	812	23	835
		Expected Count	798.5	36.5	835.0
		% within C/F Weather	97.2%	2.8%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	35.0%	21.7%	34.4%
Total		Count	2320	106	2426
		Expected Count	2320.0	106.0	2426.0
		% within C/F Weather	95.6%	4.4%	100.0%
		% within Perceptual Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

Skill based errors (Table 22) represent a statistically stronger relationship to weather factors (X^2 (1, n=2426) = 14.939, p<.001) than perceptual errors, as evidenced by the larger difference in the percentage of skill based error accidents that do not involve weather (67.7%) versus those that do (32.3%).

Table 22: Association of weather factors and skill based errors

			Skill-Based Errors (Unsafe Acts - Errors)		
			0	1	Total
C/F Weather	0	Count	357	1234	1591
		Expected Count	396.1	1194.9	1591.0
		% within C/F Weather	22.4%	77.6%	100.0%
		% within Skill-Based Errors (Unsafe Acts - Errors)	59.1%	67.7%	65.6%
	1	Count	247	588	835
		Expected Count	207.9	627.1	835.0
		% within C/F Weather	29.6%	70.4%	100.0%
		% within Skill-Based Errors (Unsafe Acts - Errors)	40.9%	32.3%	34.4%
Total		Count	604	1822	2426
		Expected Count	604.0	1822.0	2426.0
		% within C/F Weather	24.9%	75.1%	100.0%
		% within Skill-Based Errors (Unsafe Acts - Errors)	100.0%	100.0%	100.0%

CHAPTER 4

DISCUSSION

The present study of fatal GA accidents examined literally hundreds of different unsafe acts by pilots, perhaps suggesting that, correspondingly, there are literally hundreds of unique ways to crash an airplane. The results of this study, however, demonstrates that these accidents that may appear to be unique on their surface can be grouped based upon the underlying cognitive mechanisms of pilot errors. By applying a theoretically based model of unsafe acts, we are able to highlight unique global trends and identify the human error categories that contribute to GA fatalities.

Error Analysis

Recoding of NTSB data using the revised taxonomy of unsafe acts allowed for similar error forms and causal factors across accidents to be identified and the major human causes of the reviewed accidents to be discovered. Findings relating to each type of unsafe act will be discussed in turn.

Skill based errors. Accidents attributable, at least in part, to skill based errors comprise nearly 80% of aircrew error accidents, were seminal in 51% of accidents studied, and often occurred in the absence of any other error type. This finding supports our hypothesis and corroborates previous findings that skill based errors are the most prevalent form of aircrew error in both commercial and military aviation accidents (Wiegmann & Shappell, 1997; Wiegmann & Shappell, 1999; Wiegmann & Shappell, 2001a; Wiegmann & Shappell, 2001b).

Further, the present study found that skill based errors were generally more prevalent in GA than in other domains.

The most common skill based errors identified in this study include not maintaining airspeed (19.2%), improper control or handling of the aircraft (15.3%), the occurrence of a stall or spin (14.6%), and improperly maintaining altitude (12.7%). Furthermore, these categories of skill based errors occur more frequently than any other error category in the database. Each of these four skill based error categories may be attributed to failures of the pilot to monitor crucial flight parameters, a fundamental aspect of cockpit task management (Funk, 1991).

If a pilot is interrupted or distracted by a situation or event, they can quickly become sidetracked from the primary task of flying the airplane. These intrusions, uncertainties, and general distractions may keep the pilot from effectively monitoring such parameters as airspeed or altitude, and result in an error that is coded within the skill based error categories above. These insidious effects of distractions can quickly sidetrack any pilot and lead to potentially disastrous mistakes (Loukopoulos, Dismukes, & Barshi, 2001).

The larger proportion of GA fatalities involving skill based errors as compared with military and commercial aviation may, at its root, be due to lower levels of experience and training accomplished by GA pilots. General aviation pilots also fly less frequently than military or commercial pilots such that recency of experience is less. According to models by Reason (1990) and Rasmussen

(1982), skill based errors, by definition, occur during the execution of a highly routine event. This level of behavior is possible only through repetition and with experience. The lack of proficiency of many GA pilots does not allow for effective multitasking and successful workload management that military and commercial pilots display.

Many factors can have great impact on pilot effectiveness. Such factors of attention, time-sharing, and workload (Wickens & Hollands, 2000) may contribute to a breakdown in attention or memory, and resultantly appear within an accident event sequence as skill based errors. The skill of resource allocation may be one that GA pilots simply are not experienced or trained enough to master, lacking the proficiency to successfully monitor several aeronautical factors concurrently without inappropriately disregarding crucial parameters such as airspeed, aircraft control, and altitude. One can imagine a situation where an increased workload inflight quickly overcomes an inexperienced pilot and diminishes his or her capacity to monitor altitude, fuel state, visual clearance, communication, or directional control. The failures of attention that result from a high workload situation could appear within an accident causal sequence as misjudging descent rates, failures to accomplish required inflight checklist items, or the gradual inadvertent loss of airspeed, all of which appear within the most frequent categories of skill based errors in the present data.

The consistent contribution of skill based errors to fatal GA accidents over the years studied may suggest that any intervention strategies aimed to target

these errors may not have been successful. Fundamentally, through experience and effective training, pilots are able to increase their familiarity with the rules governing flight and increase their knowledge of all aspects of their domain, increase their overall proficiency, and become less prone to attention lapses or memory slips due to high workload. Other proposed ways to manage pilot workload include detailed checklists (Degani & Wiener, 1993), automation such as auditory reminders of critical tasks (Norman, 1988), and task or workload management training (Wiener, Kanki, & Helmreich, 1993).

Violations. In GA, aircrew-error accidents include violations among causal factors nearly 35% of the time. As hypothesized, this percentage was greater than those observed in military and commercial aviation analysis (Shappell & Wiegmann, 2001b[30%]; Wiegmann & Shappell, 2001a[27%]; Wiegmann & Shappell, 2001b[27%]). While military and commercial aviation involves such a vast number of policies and procedures that virtually any incorrect action is likely to result in a violation, these pilots are highly trained to follow the established rules and regulations and face the threat of organizational disciplinary action if rules are broken. General aviation by nature does not involve such a clear chain of command or responsibility, perhaps accounting for the higher proportion of violations identified in general aviation.

Perhaps the most dangerous violations are those committed purposefully but without necessity, as they represent an acceptance of unnecessary risk. These violations, comprising nearly 10% of violations within the present data,

are needlessly dangerous and unpredictable, and may characterize hazardous attitudes on the part of the pilot (Jensen, 1995). Performing unplanned maneuvers in order to show off, performing aerobatics, and buzzing the local tower are all examples of violations that are without necessity and should not be tolerated. Research suggests that social pressures may play a key role in the genesis of such violations. For example, O'Hare & Smitheram (1995) note that there are "numerous examples in the air crash files of low flying 'beat ups' and 'buzzing' that have led to disaster that would not have occurred without the presence or anticipated presence of an audience to observe the maneuvers."

Indeed, Goh & Wiegmann (2002) found that the social pressures that contribute to the violations spoken of by O'Hare and Smitheram also contribute to continued flight into adverse weather. In their study they report that GA accidents resulting from VFR flight into IMC were more likely to have passengers on board the aircraft than other types of accidents. Furthermore in a study of weather related decision making, Holbrook, Orasanu, & McCoy (2003) identify that "systemic pressures" to fly, such as those from passengers or other pilots, may "contribute to pilots' decisions to continue flight despite cues suggesting they should do otherwise" (p. 581). Further analysis is needed, however, to determine the extent to which factors such as these contributed to accidents within the present database.

The association between accidents involving violations and accidents involving weather is the only significantly positive relationship among the data

examined in this study, in that violations are more likely to be cited in connection with weather related factors. This is not a surprising trend given the vast number of violations that consist of flight into adverse weather or instrument conditions (Table 4). Bearing in mind that many GA pilots are not qualified to fly in instrument conditions (IMC), any flight into adverse weather where visibility does not meet the standards necessary for flight under visual flight rules (VFR) can be considered a violation. The question that remains, however, is why a pilot would continue flight into conditions that they know that they are not qualified to fly into.

Beyond social pressures previously addressed, O'Hare and his colleagues (O'Hare & Owen, 1999; O'Hare & Smitheram, 1995) have explored this question by investigating how pilots frame the situation of continuing or discontinuing flight into adverse weather. They found that pilots who framed diverting from a flight plan as a loss (e.g., loss of time, economic loss, or expense of effort) tend to continue flight into adverse weather, whereas those who frame a diverting decision as a gain (e.g., in personal safety) tend to divert more.

Some research (i.e., O'Hare, 1990; Goh & Wiegmann, 2002) suggests that pilot overconfidence and a limited appreciation of the risks involved with flight into adverse weather may also contribute to weather related violations, while other researchers contend that there are GA pilots who "simply do not mind taking risks and yet who also either lack the experience to assess those risks, or

perhaps have just enough experience to overestimate their own abilities" (Knecht, Harris, & Shappell, 2003; p.673).

While the percentage of accidents involving violations shows no appreciable decline over the years studied, the simplest way to reduce the occurrence of violations is through continually and consistently enforcing the rules. Unfortunately, simply enforcing rules more effectively is extremely difficult within GA due to its organizational structure. Since it is often not clear exactly whose authority GA pilots fly under (as compared with military and commercial pilots) it becomes very difficult to police the GA system. Various other means have been proposed by researchers to reduce the occurrence of violations, such as the education of GA pilots on the extent of the real risks of violating established rules and regulations and to address the occurrence of violations. Another proposal involves simulator training of difficult tasks such as emergencies or risky situations to illustrate to pilots the hazards and risks involved in violating rules associated with these events (Knecht et al., 2003).

While many cases of flight into adverse weather are rightfully coded as violations, there are many that may not represent a willful departure from established procedures, and are instead the result of misdiagnosis of weather conditions, improper planning, or a decision not to use preflight briefing service information. These errors represent a breakdown in the decision making process, and are thus captured within the category of decision errors.

Decision errors. Present in just less than 30% of all human factors fatalities, the number of decision errors in GA is consistent with proportions presented in analysis within other aviation domains (O'Hare et al., 1994; Murray, 1997; Shappell & Wiegmann, 2001a; Wiegmann & Shappell, 2001a; Wiegmann & Shappell, 2001b). Deeper analysis of decision errors reveals that 86% of decisions are coded as improper decisions, whereas just over 7% are classified as delayed or late decisions (Figure 12), generally involving planning and weather factors as well.

Recently, Burian, Orasanu, and Hitt (2000) found that 28% of accidents involving weather events involved plan continuation errors, and suggest that pilots with less experience may "not trust what their eyes are telling them and so proceed on blindly" (p. 25). Wiegmann, Goh, and O'Hare (2002) also studied the occurrence of plan continuation errors of VFR flight into IMC and present findings that suggest that under certain conditions these errors are more often attributable to poor situation assessment (early stages of information processing) than to motivational judgment.

It is delayed decisions that are perhaps the most disconcerting class of decision error, as the information necessary to reach a correct conclusion and make an appropriate decision is available to the pilot or crew. While the present analysis reveals that 7% of decision errors clearly represent delayed decisions, it is unclear from current data to what degree the 86% of decision errors categorized as improper are made due to inaccurate or inadequate information

and how many are accurate decisions that were not fully executed. Decisions made, whether accurately or inaccurately, but not implemented could also be considered to be delayed decisions if the data allowed for such a determination to be made.

Contrary to our hypothesis, decision errors do not make up a larger proportion of seminal unsafe act accidents as we expected and as Orasanu has discussed (1993). One possible explanation lies in the distinction that the present study makes between violations and decision errors that previous studies have not, referring to both simply as errors in judgment. In their study, Wiegmann & Shappell (1997) classified many errors as decision errors within the information processing and S-R-K models that were classified as violations within Reason's taxonomy of unsafe acts. Within the present data, it is worthwhile to note that when the categories are combined, decision errors and violations account for over 43 % of seminal errors.

Decision error related accidents were not found to have notable associations with the other unsafe act categories (beyond the negative association with skill based error accidents that has been addressed earlier) or with weather related accidents, but was found to have a significant negative association to accidents involving maintenance or mechanical failures. Again, this is contrary to what may be expected given research and models of decision error such as the model presented by Orasanu (1993) in Figure 3.

Orasanu's model of decision making accounts for errors based on the clarity of presentation of the situation before the decision maker. Given that mechanical malfunctions or maintenance errors can and often do occur suddenly and in an ill-defined manner, the Orasanu model might predict a positive association between decision errors and maintenance and mechanical factors. Given that the present study does not yield such an association, but instead reveals a negative association between the two, problem definition may not play as large a role in aeronautical decision making as perhaps expected, or the data simply may not reflect the extent to which it truly does. Other reasons for the present finding may involve the small number of accidents that involve these factors, and the possibility that accident investigators who are GA pilots themselves, may be reluctant to cite a decision error when a maintenance or mechanical error has already occurred.

Unlike skill based errors and violations, a decline is observed in the contribution of decision errors to accidents over the nine years studied here. This decline may suggest that the concerted efforts to improve aeronautical decision making in the 1990's may have had a positive impact (FAA, 1991). Although statistically significant, there is little operational significance of the decrease from 34.1% (1990) to 25.6% (1998), and further improvements can be made.

Proposals for ways of improving pilots' decision making abilities often involve training in aeronautical decision making. In a study of weather related

decision making, Wiggins & O'Hare (2003) state that novices may lack a full understanding of the significance of some weather related cues during inflight decision making. By examining techniques used by expert pilots to assess situations and solve problems is leading to the development of better training methods. For example, Wiggins and O'Hare (2001) recently developed a program for the FAA that uses static weather images and short video clips to help teach pilots how to more effectively identify critical weather cues. Based on initial evaluations, the computer based training program shows positive effects on aeronautical decision making.

Another method of assisting in pilot decision making is the implementation of planning aids. Layton, Smith, & McCoy (1994) evaluated the effectiveness of three different planning aid (cooperative) systems and demonstrate that different system design concepts can strongly influence the cognitive processes and resultant performance. Through their findings, the researchers recommend further research into better information displays, geographical interfaces of alternative route manipulation, access to more complete and accurate weather and traffic information, and optimization technologies to assist users in generating alternative plans. Other researchers also encourage further study of the improved design of displays that present critical data such as weather, traffic, and other environmental information (Wickens & Hollands, 2000).

Perceptual errors. As hypothesized, perceptual errors contribute to the smallest percentage of accidents within the present analysis (4.6%), found less

frequently than in both commercial and military research (Wiegmann & Shappell, 2001a [14%]; Wiegmann & Shappell, 2001b [20%]). Given the non-tactical, non-aerobatic, and often non-instrument dependent nature of GA flight, spatial disorientation and difficulties in perception are expected to occur at a lower frequency than is found within military aviation, particularly within the dynamic domains of fighter, tactical, aerobatic, or night operating aircraft.

Due to the relatively small numbers of perceptual errors coded within the general aviation accidents studied, it is difficult to substantiate prospective perception error trends or tendencies. It is clear through analysis of Table 8 that errors involving misjudging information comprise the majority of perceptual errors (61%) and represent misperception as opposed to non-detection. Analogous to decision errors made in the presence of correct and adequate information, misperception errors are disheartening as pilots inaccurately code or improperly process accurate cues from the environment. The misjudging of altitude, distance, or descent comprises a large proportion of the perceptual errors cited within the present database. Much like skill based errors, these perceptual errors may be as a result of degraded skills due to lack of recency or overall experience.

Errors of perception are found to have either no association or a negative association with the other unsafe act categories. This means that perceptual errors are either no more common in the presence of other unsafe acts or are found to be less common when other unsafe act factors are cited. Perhaps

slightly surprising is the fact that perceptual errors are found to have a negative association with weather factors. It would be expected, given the positive association between weather and violations of flight into adverse weather, that perceptual errors including spatial disorientation would be concurrently cited.

This apparent anomaly may be due to various biases and tendencies such as concluding accident analysis once one causal factor has been cited, a lack of knowledge of investigators, the system of coding data for the present study, or the present level of analysis. The following discussion addresses each of these.

Potential Biases in Data Collection

It is worthwhile to address areas throughout the data gathering process where certain biases or tendencies may exist. The discussion of the present study has already alluded to aspects of the database that appear, on their surface, to be discrepant with other conclusions drawn from other research within the aviation safety domain. Examples of these apparent discrepancies that will be specifically addressed are the surprisingly low number of accidents which involve spatial disorientation (0.16% in the present study versus 14% [CAMI, 1999]), the coding of VFR flight into IMC as skill based errors and violations (rather than as decision errors as in Shappell & Wiegman, 2001a; Shappell & Wiegmann, 2001b, Wiegmann & Shappell, 2001a; Wiegmann & Shappell, 2001b; Wiegmann, Goh, & O'Hare, 2002), and the apparent lack of fatal accidents due at least in part to communication, air traffic control (ATC), or

other crew resource management errors as compared to previous research (Wiener, 1988).

There are two times that data has been "filtered" where potential biases may have influenced the nature of how errors were categorized. We refer to these two stages as the investigative filer and the coder filter. Further, the level of analysis of the present study allows for a thorough review of unsafe acts, but serves as an objective level of filtering of the data as we disregard any other levels of human involvement that are not considered to be unsafe acts.

The investigative filter. Chronologically, the first opportunity for biases to affect the content of the present database is the NTSB investigators who determine the causes and contributing factors to the GA accidents we study here. Two potential biases may influence investigators, namely the reluctance to code multiple causes in accidents, and the reluctance to code a cause or factor that they are not confident in defending.

Investigators may be satisfied when they have identified one cause of an accident, and may conclude their investigation with only that cause. This tendency could impact the results of data analysis as factors contributing to accidents would be overlooked if only those coded as causes were considered. The present study attempts to circumvent this bias through the statistical analysis of events coded by the NTSB as both causes and contributing factors to accidents. This way, if investigators tend toward a minimal number of causes for each accident, other contributing factors will still be captured for analysis

through the inclusion of secondary factors in the database. In this respect, the present data reveals an average of nearly 3 cause factors cited for each accident.

Compared to military pilots, GA pilots do not receive the same quantity or quality of training in areas dealing with errors of perception such as physiological training in balance and orientation, spatial disorientation training, or flight training of recovery of the aircraft from unusual attitudes (Reinhart, 1996). As GA pilots become GA investigators, it may be the case that when a perceptual error occurs an investigator may not recognize it or may be hesitant to cite it as a cause or factor that they may have to defend before peers and superiors before the results of the investigation are finalized.

Investigators may also be reluctant to cite events or occurrences as causes or contributing factors if they are not fully confident in their psychological understanding of the nature of the particular error. For example, if an investigator has limited experience or formal training on issues involving spatial disorientation, it may be unlikely that spatial disorientation will be cited as a cause or factor within their investigations. This bias may occur in the form of conscious effort to avoid citing and thus being called to defend causal factors with which an investigator is not fully confident, or may be a more subtle omission of factors that are not simply not familiar to, and therefore unlikely to be used by, the investigator.

One of the goals of the larger scale FAA research project is to identify idiosyncratic areas of the investigation process and to develop interventions that

will allow for a greater sensitivity to human error related factors that currently contribute to many GA accidents. This involves training investigators in the nature and causes of human error and the factors contributing to unsafe acts. By improving the error identification process, the investigative bias can be reduced.

The coder filter. The pilot-coders used to classify NTSB data into the categories used for the present study have similar areas of potential biases, but for the coders the biases are those of interpretation of data already present. An investigator's biases affect the content of the database, as they determine what events were likely to be causes of accidents, whereas coders' biases effect the classification of data. Throughout the classification process, no information was added or taken away from that presented in finalized NTSB accident reports, so the content of the data is preserved.

Coders may have a bias to classify causes and factors into those categories with which they are more familiar, and thus avoid a situation where they would have to explain a decision regarding a subject with which they are not extremely confident or comfortable. An attempt is made to mitigate the effects of this tendency by the coding of NTSB data by two independent coders. Upon comparison of their work, any discrepancies were worked out between the coders in a manner such that the discomfort of defending decisions was minimal. The coding process, while potentially subjective and prone to personal biases, was found to be reliable.

The revised taxonomy of unsafe acts produces a high level of agreement among the accident coders and investigators who participated in this study, even after only a short formal training in human factors classification and the theoretical background of each unsafe act categories. Furthermore, even after this level of agreement between investigators was corrected for chance, the obtained reliability index is considered "excellent" by conventional standards (Cohen's kappa = .80). This reliability index is as high or higher than those observed in studies of commercial and military aviation accidents (Shappell & Wiegmann, 1997; Wiegmann & Shappell, 2001). The reliability of the pilot-coders used in this study is not a guarantee of high validity as the group may have been consistently biased throughout the coding process. The five pilots used to code the present data are subject matter experts within the field of aviation, and thus have a high level of experience and familiarity with piloting, the aviation environment, and related jargon and technical terms. Since the pilot-coders are not subject matter experts within the domain of psychology or with the psychological constructs that underlie error analysis, the overall pattern of human error may reflect only superficial knowledge of error mechanisms. Nonetheless, it was important that GA pilots be used to code the present data.

Data coded for this study was drawn from NTSB investigation reports that are often highly technical in nature, requiring a fundamental understanding of technical terms, flight conditions, and the overall domain of aviation to be effectively classified and coded. As aviation subject matter experts, the pilot-

coders were able to clearly understand each component of the investigation reports studied. Furthermore, the pilot-coders represent the end users of improved error analysis methods for conducting accident investigations, as it is aviation experts who investigate aviation accidents. Although it may be expected that subject matter experts from the domains of psychology and aviation would classify human error data somewhat differently, one earlier study previously addressed this issue by comparing the coded database of a commercial pilot rater to that of a psychologist and found the data to be reliable (Wiegmann & Shappell, 2001b).

Level of analysis. As previously described, the present study examines only those causes or contributing factors that are classified as unsafe acts by the aircrew. There are a number of categories of accident cause factors that involve humans and human error that are not unsafe acts, and are therefore neither examined nor represented within the auspices of the current data.

Communication errors are an example of human error based factors that are not considered to be unsafe acts within the present taxonomy, and are thus not presented within this study. The category of crew resource management (CRM) includes errors of communication between pilots and their crew, other pilots, and air traffic controllers, and is classified as "preconditions for unsafe acts" within other taxonomies (Shappell & Wiegmann, 2001a) from which the revised taxonomy of unsafe acts is derived, and are thus not represented within the present database, although found to contribute to 30% of accidents in

previous research (Wiegmann & Shappell, 2001b). It is probably the case that if errors of communication were consistently classified as perceptual errors, rather than as CRM errors, the former would be a larger percentage than is found in the current database.

Similarly, spatial disorientation is a factor that should not appear within the present data as it in itself is not an unsafe act, but an adverse physiological state. Misperceptions, visual illusions, and other forms of spatial disorientation are noticeably (but not entirely) absent from the current data, but set the stage for factors that are captured within the categories of unsafe acts. Examples of these resultant factors include not maintaining proper airspeed, failure to maintain altitude, or the occurrence of a stall or spin.

Many other important human-factors related accident causes are also captured within other levels of error classification, such as fatigue, alcohol use, self medication (use of over-the-counter medications), workload, medical history, and work environment. While important human factors, these are also not considered to be unsafe acts and are not examined within the present study, and further analyses of these factors are needed.

CHAPTER 5

CONCLUSION

Summary of Findings

Aircraft accidents result in losses of vital resources such as people and equipment. It is difficult to accurately assess the annual cost of compensation claims, aircraft replacement, adverse publicity, and investigation hours. Social costs such as grief for friends and loved ones and the cost of losing skilled and valued workers is simply not quantifiable. It is equally difficult to weigh the cost of accident prevention against its benefits, as it is not often possible to identify those accidents which do not occur as a result of accident prevention measures.

The purpose of the present study was to show the utility and the challenges of applying a theoretically based model of human error, namely a revised taxonomy of unsafe acts, to existing accident data. After recoding existing databases using the revised taxonomy, accident data was analyzed and revealed global trends based on cognitive theory, models of information processing, and decision making. It is through these results that the roots of human error and accident causation begin to surface, allowing researchers an insight into true causes of GA accidents.

Present research finds that most GA fatalities have at their root errors based in pilot skill, as has been found within commercial and military domain research. Decision errors and violations each contribute to approximately one third of GA fatalities, a proportion less than most previous research of military

and commercial aviation. Perceptual errors, as coded within the present database, were found to be causal to very few GA fatalities, similar to other civil aviation domains but less than originally hypothesized.

Analysis of associations among unsafe acts and between unsafe acts and environmental factors revealed that the only significant positive association present in the current data is between weather and violations. This association indicates that GA pilots are more likely to make a violation when weather is cited as a cause or factor in the accident sequence.

Implications for Safety Intervention

The high level of safety currently achieved aviation operations should not obscure the fact presented here that many aviation accidents are preventable. It is important to realize that safety measures and defenses currently in place in GA may be inadequate, circumvented, or perhaps ignored, and that the intervention strategies aimed at reducing the occurrence or consequences of human error may not been as effective as possible.

The results of the present study point to several ways to reduce the rate of GA fatalities. Skill based errors can be strategically targeted through implementation of automation systems, improved checklists, and workload management training. Further recommendations to improve GA flight safety include improved training on the effect of risk, violations, and aeronautical decision making, as well as the improvement of display design, the use of automation systems to reduce pilot workload, and simulator training of difficult

or risky situations. Through application of the results of the present study, continued research into the human error causes of accidents, and continued progress applying human error theory to existing databases, further improvements can be made to an already impressive aviation safety record.

BIBLIOGRAPHY

Backman, L., & von Hofsten, C. (Eds.). *Psychology at the turn of the millennium Vol. 1: Cognitive, biological, and health perspectives.* New York: Psychology Press.

Billings, C.E., & Reynard, W.D. (1984). Human factors in aircraft incidents: Results of a 7-year study. *Aviation, Space, and Environmental Medicine,* 55, 960-965.

Brenner, C. (1957). *An elementary textbook in psychoanalysis.* New York: Doubleday.

Bryan, L.A., Stonecipher, J.W., & Aron, K. (1954). *180 degree turn expiriment.* University of Illinois Institute of Aviation Aeronautics bulletin number 11. Urbana, IL: University of Illinois Press.

Burian, B., Orasanu, J., & Hitt, J. (2000). Weather-related decision errors: differences across flight types. *Proceedings of the XIVth triennial Congress of the International Ergonomics Association/44th annual meeting of the Human Factors and Ergonomics Society* (pp. 22-24). Santa Monica, CA: Human Factors and Ergonomics Society.

Card, S., Moran, T.P., & Newell, A. (1983). *The psychology of human-computer interactions.* Hillsdale, NJ: Earlbaum.

Civil Aeromedical Institute (1999). *Spatial Disorientation.* Oklahoma City, OK: Federal Aviation Administration.

Conover, W.J. (1999). *Practical nonparametric statistics.* New York: Wiley & Sons.

Degani, A., & Wiener, E.L. (1993). Cockpit checklists: Concepts, design, and use. *Human Factors,* 35(4), 345-360.

Federal Aviation Administration (1991). *Aeronautical Decision Making.* Advisory Circular 60-22.

Ferry, T.S. (1988). *Modern accident investigation and analysis* (2nd ed.). New York: Wiley.

Fitts, P.M., & Jones, R.E. (1947). Analysis of factors contributing to 460 "pilot-error" experiences in operating aircraft controls. Report TSEAA-694-12, Aeromedical Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio. Reprinted in W.H. Sinaiko (Ed.), *Selected papers in on human factors in the design and use of control systems.* New York: Dover.

Fleiss, J. (1981). *Statistical methods for rates and proportions.* New York: Wiley & Sons.

Funk, K.H. (1991). Cockpit task management: Preliminary definitions, normative theory, error taxonomy, and design recommendations. *The International Journal of Aviation Psychology*, 1(4), 271-285.

Goh, J., & Wiegmann, D.A. (2002). Human error analysis of accidents involving visual flight rules flight into adverse weather. *Aviation, Space, and Environmental Medicine*, 78(8), 817-822.

Haddon, W., Suchman, E.A., & Klein, D. (1964). *Accident research: Methods and approaches.* New York: Harper & Row.

Hayter, W. (1976). *Spooner: A Biography.* London: W.H. Allen.

Heinrich, H.W., Petersen, D., & Roos, N. (1980). *Industrial accident prevention: A safety management approach* (5^{th} ed.). New York: McGraw-Hill.

Holbrook, J.B., Orasanu, J.M., & McCoy, C.E., (2003). Weather-related decision making by aviators in Alaska. *Proceedings of the 12^{th} International Symposium on Aviation Psychology.*

International Civil Aviation Organization (1984). Accident prevention manual, Montreal, Canada: ICAO.

International Civil Aviation Organization (1993). Investigation of human factors in accidents and incidents (Human Factors Digest #7), Montreal, Canada: ICAO.

Jensen, R.S. (1995). *Pilot judgment and crew resource management.* Brookfield, VT: Ashgate Publishing Company.

Johnson, E.M., Cavenaugh, R.C., Spooner, R.L., & Samet, M.G. (1973). Utilization of reliability estimates in Bayesian inference. *IEEE Transactions on Reliability*, 22, 176-183.

Jones, A.P. (1988). Climate and measurement of consensus: A discussion of 'organizational climate.' In S.G. Cole, R.G. Demaree, & W. Curtis (Eds.), *Applications of interactionist psychology: Essays in honor of Saul B. Sells* (pp. 283-290). Hillsdale, NJ: Earlbaum.

Knecht, W., Harris, H., & Shappell, S. (2003). Effects of visibility, cloud ceiling and financial incentive on general aviation voluntary takeoff into adverse weather. *Proceedings of the 12th International Symposium on Aviation Psychology.*

Layton, C., Smith, P.J., & McCoy, E. (1994). Design of a cooperative problem-solving system for en-route flight planning: An empirical evaluation. *Human Factors*, 36(1), 94-119.

Li, G., & Baker, S.P. (1999) Correlates of pilot fatality in general aviation crashes. *Aviation, Space, and Environmental Medicine*, 61, 265-270.

Loukopoulos, L.D., Dismukes, R.K., & Barshi, I. (2001). Cockpit interruptions and distractions: A line observation. *Proceedings of the 11th International Symposium on Aviation Psychology.*

Martin, J.D. (1993). Flying safety: We've come a long way. *Flying Safety*, November.

Maurino, D.E., Reason, J., Johnston, N., & Lee, R.B. (1995). *Beyond aviation human factors.* Brookfield, VT: Ashgate Publishing Company.

Murray, S.R. (1997). Deliberate decision making by aircraft pilots: A simple reminder to avoid decision making under panic. *The International Journal of Aviation Psychology*, 7(1), 83-100.

Muthard, E.K., & Wickens, C.D. (2003). Factors that mediate flight plan monitoring and errors in plan revision: Planning under automated and high workload conditions. *Proceedings of the 12th International Symposium on Aviation Psychology.*

Mynatt, C.R., Doherty, M.E., & Tweney, R.D. (1977). Confirmation bias in a simulated research environment: An experimental study of scientific inference. *Quarterly Journal of Experimental Psychology*, 29, 85-95.

Nagel, D.C. (1988). Human error in aviation operations. In E.L. Wiener & D.C. Nagel (Eds.), *Human factors in aviation* (pp. 263-303). San Diego, CA: Academic.

National Safety Council (1997). *Accident facts.* Itasca, IL: National Safety Council.

National Transportation Safety Board (2001b). Aviation accident statistics. [On-line]. Available: www.ntsb.gov/aviation/Stats.htm.

National Transportation Safety Board (2003a). Accidents, Fatalities, and Rates, 1982 through 2001, for U.S. Air Carriers Operating Under 14 CFR 121, Scheduled and Nonscheduled Service (Airlines). [On-line]. Available: www.ntsb.gov/aviation/Table5.htm.

National Transportation Safety Board (2003b). Accidents, Fatalities, and Rates, 1982 through 2001, for U.S. Air Carriers Operating Under 14 CFR 135, Scheduled Service. [On-line]. Available: www.ntsb.gov/aviation/Table8.htm.

National Transportation Safety Board (2003c). Accidents, Fatalities, and Rates, 1982 through 2001, U.S. General Aviation. [On-line]. Available: www.ntsb.gov/aviation/Table10.htm.

Norman, D.A. (1981). Categorization of action slips. *Psychological Review*, 88, 1-15.

Norman, D.A. (1983). Design rules based on analysis of human error. *Communications of the ACM*, 26, 254-258.

Norman, D.A. (1988). *The Psychology of Everyday Things.* New York: Basic Books.

O'Hare, D. (1990). Pilots' perception of risks and hazards in general aviation. *Aviation, Space, and Environmental Medicine*, 61, 599-603.

O'Hare, D., & Owen, D. (1999). *Continued VFR into IMC: An empirical investigation of the possible causes: Final report on preliminary study.* Unpublished manuscript. University of Otago, Dunedin, New Zealand.

O'Hare, D., & Smitheram, T. (1995). "Pressing on" into deteriorating conditions: An application of behavioral decision theory to pilot decision making. *International Journal of Aviation Psychology,* 5, 351-370.

O'Hare, D., Wiggins, M., Batt, R., & Morrison, D. (1994). Cognitive failure analysis for aircraft accident investigation. *Ergonomics,* 37(11), 1855-1869.

Orasanu, J.M. (1993). Decision-making in the cockpit. In E.L. Wiener, B.G. Kanki, & R.L Helmreich (Eds.), *Cockpit resource management* (pp. 137-172). New York: Academic Press.

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents*, 4, 311-333.

Rasmussen, J. (1983). Skills, rules, knowledge: Signals, signs and symbols, and other distinctions in human performance models. *IEEE Transactions: Systems, Man, & Cybernetics*, SMC-13, 257-267.

Rasmussen, J. (1988). Interdisciplinary workshops to develop a multidisciplinary research programme based on a holistic system approach to safety and management of risk in large-scale technological operations. Paper commissioned by World Bank, Washington D.C.

Reason, J. (1984). Lapses of attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention*. New York: Academic Press.

Reason, J. (1987). The Chernobyl errors. *Bulletin of the British Pshcyological Society*, 40, 201-206.

Reason, J. (1990). *Human error.* New York: Cambridge University Press.

Reason, J. (1997). *Managing the risks of organizational accidents.* Brookfield, VT: Ashgate Publishing Company.

Reason, J.T., & Mycielska, K. (1982). *Absent minded? The psychology of mental lapses and everyday errors*. Englewood Cliffs, NJ: Prentice-Hall.

Reinhart, R.O. (1996). *Basic Flight Physiology*. New York: McGraw-Hill.

Sarter, N.B., & Alexander, H.M. (2000). Error types and related error detection mechanisms in the aviation domain: An analysis of aviation safety reporting system incident reports. *The International Journal of Aviation Psychology*, 10(2), 189-206.

Sellen, A.J. (1994). Detection of everyday errors. *Applied Psychology: An International Review*, 43(4), 475-498.

Shappell, S.A., & Wiegmann, D.A. (1996). U.S. naval aviation mishaps, 1977-92: Differences between single- and dual-piloted aircraft. *Aviation, Space, and Environmental Medicine*, 67(1), 65-69.

Shappell, S.A., & Wiegmann, D.A. (1997). A human error approach to accident investigation: The taxonomy of unsafe operations. *The International Journal of Aviation Psychology*, 7(4), 269-291.

Shappell, S.A., & Wiegmann, D.A. (2001a). Applying Reason: The human factors analysis and classification system (HFACS). *Human Factors and Aerospace Safety*, 1(1), 59-86.

Shappell, S.A., & Weigmann, D.A. (2001b). Unraveling the mystery of general aviation controlled flight into terrain accidents using HFACS. *Paper presented at the 11th International Symposium on Aviation Psychology.*

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judgment frequency probability. *Cognitive Psychology*, 5, 207-232.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185, 1124-1131.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, 211, 453-458.

United States Air Force (2001). *Medical examinations and standards.* Air Force Instruction 48-123. Washington D.C.: USAF.

United Stated Air Force (2003). USAF History, CY47-FY01. [On-line]. Available: http://safety.kirtland.af.mil/AFSC/RDBMS/Flight/stats/usaf1097.html

Wagenaar, W.A., & Groeneweg, J. (1987). Accidents at sea: Multiple causes and impossible consequences. *International Journal of Man-Machine Studies*, 27, 587-598.

Wason, P.C., & Johnson-Laird, P.N. (1972). *Psychology of reasoning: Structure and content.* London: Batsford.

Wickens, C.D. (1984). *Engineering psychology and human performance* (3rd ed.). Columbus, OH: Charles Merrill.

Wickens, C.D. (2002). Aviation psychology. In L. Backman & C. von Hofsten (Eds.), *Psychology at the turn of the millennium Vol. 1: Cognitive, biological, and health perspectives* (pp. 545-573). New York: Psychology Press.

Wickens, C.D., & Flach, J.M. (1988). Information processing. In E.L Wiener & D.C. Nagel (Eds.), *Human factors in aviation* (pp. 111-155). San Diego, CA: Academic.

Wickens, C.D., & Hollands, J.G. (2000). *Engineering psychology and human performance.* Upper-Saddle River, NJ: Prentice-Hall.

Wiegmann, D.A., Goh, J. & O'Hare, D. (2002). The role of situation assessment and flight experience in pilots' decisions to continue visual flight rules flight into adverse weather. *Human Factors*, 44(2), 189-197.

Wiegmann, D.A., & Shappell, S.A. (1997). Human factors analysis of postaccident data: Applying theoretical taxonomies of human error. *The International Journal of Aviation Psychology*, 7(1), 67-81.

Wiegmann, D.A., & Shappell, S.A (1999). Human error and crew resource management failures in naval aviation mishaps: A review of U.S. Naval Safety Center data, 1990-96. *Aviation, Space, and Environmental Medicine*, 70(12), 1147-1151.

Wiegmann, D.A., & Shappell, S.A. (2001a). Applying the human factors analysis and classification system (HFACS) to the analysis of commercial aviation accident data. *Paper presented at the 11th International Symposium on Aviation Psychology.*

Wiegmann, D.A., & Shappell, S.A. (2001b). Human error analysis of commercial aviation accidents: Application of the human factors analysis and classification system (HFACS). *Aviation, Space, and Environmental Medicine*, 72(11), 1006-1016.

Wiegmann, D.A., & Shappell, S.A. (2001c). Human error perspectives in aviation. *International Journal of Aviation Psychology,* 11(4), 341-357.

Wiegmann, D.A., Shappell, S.A., Cristina, F., & Pape, A. (2000). A human factors analysis of aviation accident data: An empirical evaluation of the HFACS framework. *Aviation, Space, and Environmental Medicine*, 71, 328.

Wiener, E.L. (1985). Beyond the sterile cockpit. *Human Factors*, 27, 75-90.

Wiener, E.L. (1988). Cockpit Automation. In E.L Wiener & D.C. Nagel (Eds.), *Human factors in aviation* (pp. 433-461). San Diego, CA: Academic.

Wiener, E.L., & Nagel, D.C. (Eds.) (1988). *Human factors in aviation.* San Diego, CA: Academic.

Wiener, E.L., Kanki, B.G., & Helmreich, R.L. (Eds.) (1993). *Cockpit Resource Management.* San Diego, CA: Academic Press.

Wiggins, M., & O'Hare, D. (2003). Expert and novice pilot perceptions of static in-flight images of weather. *The International Journal of Aviation Psychology,* 13(2), 173-187.

Wiggins, M., & O'Hare, D. (Draft year 2001). *Weatherwise: Evaluation of a computer-based training program for weather-related pilot decision making.* Manuscript submitted for publishing.

Wright, R.E. (1974). Aging, divided attention, and processing capacity. *Journal of Gerontology,* 36, 605-614.

Yacavone, D. (1993). Mishap trends and cause factors in Naval aviation: A review of Naval Safety Center data, 1986-1990. *Aviation, Space, and Environmental Medicine,* 64, 392-395.

APPENDIX A

SKILL BASED ERROR CODES

aborted takeoff improper
ac control abrupt
ac control excessive
ac control improper
ac control inadequate
ac control not maintained
ac control not maintained obtained
ac control not possible
ac control uncontrolled
ac handling abrupt
ac handling excessive
ac handling improper
ac handling inadequate
ac handling not maintained
ac handling uncontrolled
ac protective covering not removed
ac weight and balance
ac weight balance exceeded
ac weight balance excessive
ac weight balance improper
aerobatics not maintained
aerobatics performed
aileron improper use of
air ground communication inadequate
air speed diminished
air speed exceeded
air speed excessive
air speed improper
air speed inadequate
air speed low
air speed misjudged
air speed not attained
air speed not attained maintained
air speed not corrected
air speed not maintained
air speed not obtained
air speed not obtained maintained
aircraft control not maintained
aircraft weight and balance exceeded
airspeed (VMC) not maintained
airspeed exceeded
airspeed excessive
airspeed inadequate
airspeed not maintained
altimeter misread
altimeter not set
altimeter setting improper
altitude clearance inadequate
altitude clearance not maintained
altitude clearance not obtained maintained
altitude excessive
altitude improper
altitude inaccurate
altitude inadequate
altitude inadequate copilot
altitude misjudged
altitude not attained
altitude not maintained
altitude/clearance inadequate
altitude/clearance not maintained
anti ice de ice system improper use of
approach receiver improper
auto pilot improper use of
became lost disoriented
became lost/disoriented
brakes excessive
brakes improper use of
carburettor heat improper use of
carburettor heat not removed
carburettor heat not selected
carburettor heat not used
caution warning system light not identified
check list disregarded
checklist not followed
checklist not used
clearance inadequate
clearance not attained
clearance not followed
clearance not maintained
clearance not maintained p2
clearance not obtained maintained
climb excessive
climb inadequate
climb not maintained
climb not obtained
climb not performed
climb not understood
climb rate not obtained maintained
compensation for wind conditions improper
compensation for wind conditions inadequate
compensation for wind conditions not attained
compensation for wind conditions not performed
compensation for wind conditions poor

decision height below
decision height inadvertent
decision height not attained
decision height not used
descent excessive
descent inadvertent
descent not corrected
design stress limits of ac exceeded
directional control not attained
directional control not identified
directional control not maintained
directional control not possible
directional control reduced
distance altitude not maintained
distance speed misjudged
diverted attention
elevator trim excessive
elevator trim improper use of
elevator trim not corrected
elevator trim not used
emergency procedure improper
emergency procedure inadequate
emergency procedure not attained
emergency procedure not followed
emergency procedure not performed
emergency procedure poor
emergency procedures not followed
flaps improper use of
flaps not used
flare improper
flare not attained
flare not performed
flight controls improper use of
flight into adverse weather encountered
flight into adverse weather inadvertent
flight into adverse weather performed
formation flying improper
fuel boost pump selector position improper
fuel consumption calculation improper
fuel consumption calculation inaccurate
fuel consumption calculation inadequate
fuel consumption calculations inaccurate
fuel management improper
fuel management inadequate
fuel supply improper use of
fuel supply inadequate
fuel supply inattentive
fuel supply misjudged
fuel supply misread
fuel supply not selected
fuel tank selector position disregarded
fuel tank selector position improper
gear extension not performed
gear retraction not performed
glider tow release not performed
go around attempted
ground loop swerve inadvertent
habit interference student
ifr procedure improper
ifr procedure misread
ifr procedure not followed
improper use of equipment/aircraft
improper use of procedure
improper use of throttle/power control
improper use weather radar
inattentive
inattentive pic
inflight planning decision improper
lack of familiarity with geographical area
landed at wrong airport inadvertent
landing at wrong airport attempted
landing lights not used
level off not attained
lift off premature
load jettison not attained
low altitude flight maneuver excessive
lowering of flaps excessive
lowering of flaps improper
lowering of flaps not performed
lowering of flaps not understood
maneuver excessive
maneuver improper
maneuver premature
maneuver to avoid obstruction abrupt
minimum descent altitude not maintained
misc eqp improper use of
misc eqp improper use of p2
misc equipment not available
missed approach not attained
missed approach not followed
missed approach not performed
mixture improper use of
mixture inadvertent use
monitoring inadequate
monitoring inadequate copilot
monitoring inadequate pic
navigation receiver improper
parking brakes improper use of
planned approach improper
planned approach not attained
planned approach poor
porpoise inadvertent
porpoise not corrected
power plant control improper use of
preflight planning preparation inadequate
procedure directives improper

procedure directives inadequate
procedure directives not followed
propeller feathering inadvertent dual
  student
propeller feathering not attained
propeller feathering not performed
propeller improper use of
proper alignment not attained
proper alignment not maintained
proper altitude not attained
proper altitude not identified
proper altitude not maintained
proper altitude not obtained maintained
proper altitude not selected
proper climb rate not attained
proper climb rate not maintained
proper climb rate not obtained
proper climb rate not performed
proper descenet rate not followed
proper descent rate exceeded
proper descent rate not attained
proper descent rate not maintained
proper glide path inadequate
proper glide path not attained
proper glide path not followed
proper glide path not maintained
proper glidepath not maintained
proper touch down point not attained
proper touchdown point not attained
pull up abrupt
pull up delayed
pull up excessive
raising of flaps improper
raising of flaps not performed
raising of flaps not understood
raising of flaps premature
recovery from bounced landing delayed
recovery from bounced landing improper
recovery from bounced landing inadequate
remedial action excessive
remedial action improper
remedial action inadequate
remedial action not performed
removal of control gust lock not performed
rotation excessive
rotation premature
rudder trim not corrected
speed inadequate
spiral inadvertent
spiral not corrected
spiral uncontrolled
stabilator improper use
stabilator trim improper
stabilizer trim excessive
stall inadvertent
stall uncontrolled
stall encountered
stall inadequate
stall inadvertent
stall intentional
stall mush encountered
stall mush inadvertent
stall mush intentional
stall mush not identified
stall not corrected
stall spin
stall spin encountered
stall spin inadvertent
stall spin intentional
stall spin not corrected
stall spin not possible
stall spin uncontrolled
stall/mush inadvertent
stall/spin inadvertent
starting procedure inadequate
throttle power control abrupt
throttle power control improper use of
transponder not used
trim setting not corrected
unicom not selected p2
unsuitable terrain or take off area
  inadvertent use
vacuum system improper use of
vfr flight into imc inadequate
vfr flight into imc inadvertent
vfr into imc encountered
vfr into imc inadvertent
vfr procedure improper
vfr procedure inadequate
vfr procedure not followed
visual aural detection
visual look out inadequate
visual look out inadequate p1
visual look out inadequate p2
visual look out inadequate p3
visual look out not maintained
visual look out not maintained p2

APPENDIX B

SKILL BASED ERROR FREQUENCIES

Skill Based Error Category	Frequency	Percent
Airspeed Not Maintained	**513**	**19.2%**
Airspeed not maintained	419	
Airspeed inadequate	60	
Airspeed not attained	8	
Airspeed not obtained/maintained	8	
Airspeed exceeded	4	
Airspeed improper	3	
Airspeed excessive	2	
Airspeed low	2	
Airspeed not obtained	2	
Airspeed diminished	1	
Airspeed misjudged	1	
Airspeed not attained/maintained	1	
Airspeed not corrected	1	
Airspeed (VMC) not maintained	1	
Aircraft Control/Handling	**410**	**15.3%**
Aircraft control not maintained	364	
Aircraft control uncontrolled	21	
Aircraft handling improper	10	
Aircraft control not possible	3	
Aircraft control inadequate	2	
Aircraft handling abrupt	2	
Aircraft control abrupt	1	
Aircraft control excessive	1	
Aircraft control improper	1	
Aircraft control not maintained/obtained	1	
Aircraft handling excessive	1	
Aircraft handling inadequate	1	
Aircraft handling not maintained	1	
Aircraft handling uncontrolled	1	
Stall/Spin	**391**	**14.6%**
Stall inadvertent	210	
Stall spin inadvertent	110	
Stall mush inadvertent	35	
Stall encountered	6	
Stall spin encountered	6	
Stall mush encountered	4	
Stall/spin inadvertent	4	
Stall spin not corrected	3	
Stall spin uncontrolled	2	
Stall inadvertent	1	
Stall uncontrolled	1	
Stall inadequate	1	
Stall intentional	1	
Stall mush intentional	1	
Stall mush not identified	1	
Stall not corrected	1	
Stall spin	1	
Stall spin intentional	1	
Stall spin not possible	1	
Stall/mush inadvertent	1	

Skill Based Error Category	Frequency	Percent
Altitude Improper/Not Maintained	**341**	**12.7%**
Altitude not maintained	132	
Altitude clearance not maintained	93	
Altitude inadequate	76	
Altitude clearance inadequate	11	
Altitude/clearance not maintained	8	
Altitude not attained	6	
Altitude improper	4	
Altitude clearance not obtained/maintained	3	
Proper altitude not identified	2	
Altitude excessive	1	
Altitude inaccurate	1	
Altitude inadequate copilot	1	
Altitude misjudged	1	
Altitude/clearance inadequate	1	
Proper altitude not selected	1	
Clearance (From Object or Aircraft) Not Maintained	**189**	**7.1%**
Clearance not maintained	177	
Clearance inadequate	7	
Clearance not obtained/maintained	2	
Clearance not attained	1	
Clearance not followed	1	
Clearance not maintained p2	1	
Visual Look Out Inadequate	**157**	**5.9%**
Visual look out inadequate	91	
Visual look out inadequate p2	33	
Visual look out not maintained	13	
Visual look out inadequate p1	10	
Visual look out not maintained	4	
Visual look out inadequate p3	3	
Visual look out not maintained p2	1	
Visual look out not performed	1	
Visual look out inadequate	1	
Fuel Mismanagement	**61**	**2.3%**
Fuel tank selector position improper	34	
Fuel consumption calculation inaccurate	6	
Fuel management improper	5	
Fuel supply not selected	3	
Fuel boost pump selector position improper	2	
Fuel management inadequate	2	
Fuel consumption calculation improper	1	
Fuel consumption calculation inadequate	1	
Fuel consumption calculation inaccurate	1	
Improper use of fuel supply	1	
Fuel supply inadequate	1	
Fuel supply inattentive	1	
Fuel supply misjudged	1	
Fuel supply misread	1	
Fuel tank selector position disregarded	1	

Skill Based Error Category	Frequency	Percent
VFR Flight Into IMC	**58**	**2.2%**
VFR into IMC inadvertent	50	
VFR into IMC encountered	5	
VFR flight into IMC inadvertent	2	
VFR flight into IMC inadequate	1	
Emergency Procedure Error	**28**	**1.0%**
Emergency procedure improper	14	
Emergency procedure not followed	7	
Emergency procedure inadequate	2	
Emergency procedure not attained	2	
Emergency procedure not performed	1	
Emergency procedure poor	1	
Emergency procedures not followed	1	
Proper Glide Path Not Maintained	**22**	**0.8%**
Proper glide path not maintained	19	
Proper glide path inadequate	1	
Proper glide path not attained	1	
Proper glide path not followed	1	

APPENDIX C

SEMINAL SKILL BASED ERROR FREQUENCIES

Seminal Skill Based Error Category	Frequency	Percent
Airspeed Not Maintained	**253**	**22.8%**
Airspeed not maintained	215	
Airspeed inadequate	30	
Airspeed excessive	2	
Airspeed not attained	2	
Airspeed diminished	1	
Airspeed improper	1	
Airspeed low	1	
Airspeed not obtained/maintained	1	
Aircraft Control/Handling	**182**	**16.4%**
Aircraft control not maintained	161	
Aircraft handling improper	8	
Aircraft control uncontrolled	5	
Aircraft control inadequate	2	
Aircraft control not possible	2	
Aircraft control abrupt	1	
Aircraft control excessive	1	
Aircraft handling abrupt	1	
Aircraft handling uncontrolled	1	
Altitude Improper/Not Maintained	**123**	**11.1%**
Altitude clearance not maintained	34	
Proper altitude not maintained	30	
Altitude inadequate	22	
Altitude not maintained	18	
Altitude clearance inadequate	6	
Altitude/clearance not maintained	6	
Altitude Improper	2	
Altitude not attained	2	
Proper altitude not attained	1	
Proper altitude not identified	1	
Proper altitude not obtained/maintained	1	
Clearance (From Object or Aircraft) Not Maintained	**103**	**9.3%**
Clearance not maintained	98	
Clearance inadequate	2	
Clearance not attained	1	
Clearance not followed	1	
Clearance not obtained/maintained	1	
Visual Look Out Inadequate	**70**	**6.3%**
Visual look out inadequate	51	
Visual look out inadequate p1	10	
Visual look out not maintained	7	
Visual look out inadequate p2	1	
Visual separation not maintained	1	

APPENDIX D

VIOLATION CODES

ac control exceeded
ac control not maintained
ac unattended engine running intentional
ac weight balance continued
ac weight balance disregarded
ac weight balance exceeded
ac weight balance excessive
ac weight balance improper
act clearance not complied
aerobatics attempted
aerobatics improper
aerobatics initiated
aerobatics intentional
aerobatics performed
air speed exceeded
airspeed exceeded
altitude clearance inadequate
altitude disregarded
altitude inadequate
altitude low
ATC clearance not followed
attitude indicator not available
below decision height
buzzing intentional
buzzing performed
certification improper for flight
decision height disregarded
decision height not complied with
decision height not maintained
decision height not used
descent height disregarded
design stress limits of ac exceeded
design stress limits of aicraft exceeded
design stress limits of aircraft exceeded
dispatch procedures not followed other govt personnel
emergency procedure not followed
external navigation lights not used
flight into adverse weather
flight into adverse weather attempted
flight into adverse weather continued
flight into adverse weather improper
flight into adverse weather inadvertent
flight into adverse weather initiated
flight into adverse weather intentional
flight into adverse weather performed
flight into adverse weather selected
flight into known adverse weather attempted
flight into known adverse weather intentional
flight manuals disregarded
flight navigation instruments inadequate
fuel supply inadequate
hazardous weather advisory disregarded
ice frost removal from ac improper
ifr procedure improper
ifr procedure not followed
impairment alcohol
impairment drugs
inflight briefing service not used
inflight planning decision improper
information insufficient designated examiner
information insufficient pic
lack of certification
loading of cargo improper
low altitude flight maneuver attempted
low altitude flight maneuver intentional
low altitude flight maneuver performed
low pass intentional
low pass performed
maintenance annual inspection not complied with
maintenance annual inspection not performed
maintenance installation improper
maintenance service bulletin not complied with
maneuver attempted
minimum descent altitude below
minimum descent altitude disregarded
minimum descent altitude not complied with
minimum descent altitude not maintained
minimum descent altitude not obtained/maintained
missed approach not followed
missed approach not performed
op with known def in eqp attempted
op with known def in eqp continued
op with known def in eqp initiated
op with known def in eqp intentional
op with known def in eqp not corrected
op with known def in eqp performed
operation with known deficiencies in equipment intention
ostentatious display
passenger briefing not performed
procedure directives disregarded
procedure directives disregarded p2
procedure directives improper
procedure directives not complied with flight crew
procedure directives not followed
procedure directives not followed p2
procedure directives not performed
procedures/directives not followed
proper altitude not maintained
proper glide path not maintained
qualification pic
qualification unqualified person
seat belt not used
seat belt unavailable passenger

security of cargo not performed
shoulder harness not used
shoulder harness unavailable
stolen ac unauthorized use performed
use of unapproved medication/drug
vfr flight into imc
vfr flight into imc continued
vfr flight into imc intentional
vfr into imc
vfr into imc attempted
vfr into imc continued
vfr into imc encountered
vfr into imc inadvertent
vfr into imc initiated
vfr into imc intentional
vfr into imc performed
vfr procedure improper
vfr procedure not followed
vfr procedures not maintained
weather forecast disregarded
weather forecast not obtained
weather forecast not received

APPENDIX E

VIOLATION FREQUENCIES

Violation Category	Frequency	Percent
VFR Flight Into IMC	**269**	**28.5%**
VFR into IMC continued	127	
VFR into IMC attempted	47	
VFR into IMC performed	34	
VFR into IMC intentional	29	
VFR into IMC initiated	17	
VFR flight into IMC continued	5	
VFR into IMC encountered	3	
VFR into IMC inadvertent	3	
VFR flight into IMC intentional	2	
VFR flight into IMC	1	
VFR into IMC	1	
Flight Into Adverse Weather	**162**	**17.1%**
Flight into adverse weather continued	54	
Flight into adverse weather performed	34	
Flight into adverse weather attempted	28	
Flight into adverse weather intentional	23	
Flight into adverse weather initiated	15	
Flight into adverse weather inadvertent	3	
Flight into adverse weather	1	
Flight into adverse weather improper	1	
Flight into adverse weather selected	1	
Flight into known adverse weather attempted	1	
Flight into known adverse weather intentional	1	
Design Stress Limits of Aircraft Exceeded	**91**	**9.6%**
Design stress limits of ac exceeded	87	
Design stress limits of aircraft exceeded	4	
IFR Procedure Not Followed	**55**	**5.8%**
IFR procedure not followed	32	
IFR procedure improper	23	
Aircraft Weight/Balance	**49**	**5.2%**
Aircraft weight/balance exceeded	42	
Aircraft weight/balance improper	4	
Aircraft weight/balance continued	1	
Aircraft weight/balance disregarded	1	
Aircraft weight/balance excessive	1	

Violation Category	Frequency	Percent
Procedures/Directives Not Followed	**47**	**5.0%**
Procedure/directive not followed	33	
Procedure/directive disregarded	6	
Procedure/directive disregarded p2	2	
Procedure/directive improper	2	
Procedure/directive not followed p2	2	
Procedure/directive not complied with (flight crew)	1	
Procedure/directive not performed	1	
Low Altitude Flight/Buzzing Performed	**46**	**4.9%**
Buzzing intentional	17	
Buzzing perfomed	13	
Low altitude flight/maneuver intentional	5	
Low altitude flight/maneuver performed	5	
Low pass intentional	3	
Low pass performed	2	
Low altitude flight/maneuver attempted	1	
Operation With Known Deficiency in Equipment	**42**	**4.4%**
Operation with known deficiency in equipment intentional	15	
Operation with known deficiency in equipment performed	9	
Operation with known deficiency in equipment attempted	8	
Operation with known deficiency in equipment continued	8	
Operation with known deficiency in equipment initiated	1	
Operation with known deficiency in equipment not corrected	1	
Aerobatics Performed	**30**	**3.2%**
Aerobatics performed	17	
Aerobatics attempted	9	
Aerobatics intentional	2	
Aerobatics improper	1	
Aerobatics initiated	1	
Minimum Descent Altitude Not Maintained	**28**	**3.0%**
Minimum descent altitude not maintained	19	
Minimum descent altitude disregarded	4	
Minimum descent altitude not complied with	3	
Minimum descent altitude below	1	
Minimum descent altitude not obtained/maintained	1	

APPENDIX F

SEMINAL VIOLATION FREQUENCIES

Seminal Violation Category	Frequency	Percent
VFR Flight Into IMC	**166**	**34.0%**
VFR into IMC continued	84	
VFR into IMC attempted	32	
VFR into IMC intentional	18	
VFR into IMC performed	17	
VFR into IMC initiated	10	
VFR flight into IMC continued	2	
VFR into IMC encountered	2	
VFR flight into IMC intentional	1	
Flight Into Adverse Weather	**97**	**19.9%**
Flight into adverse weather continued	32	
Flight into adverse weather performed	21	
Flight into adverse weather attempted	15	
Flight into adverse weather intentional	13	
Flight into adverse weather initiated	11	
Flight into adverse weather inadvertent	2	
Flight into adverse weather improper	1	
Flight into known adverse weather attempted	1	
Flight into known adverse weather intentional	1	
IFR Procedure Not Followed	**44**	**9.0%**
IFR procedure not followed	27	
IFR procedure improper	17	
Low Altitude Flight/Buzzing Performed	**30**	**6.1%**
Buzzing intentional	13	
Buzzing performed	8	
Low altitude flight maneuver intentional	3	
Low altitude flight maneuver performed	3	
Low pass performed	2	
Low altitude flight maneuver attempted	1	
Operation With Known Deficiency in Equipment	**28**	**5.7%**
Operation with known deficiency in equipment intentional	9	
Operation with known deficiency in equipment performed	8	
Operation with known deficiency in equipment continued	5	
Operation with known deficiency in equipment attempted	4	
Operation with known deficiency in equipment initiated	1	
Operation with known deficiency in equipment not corrected	1	

APPENDIX G

DECISION ERROR CODES

abort above v1 performed
abort not performed
aborted landing delayed
aborted landing initiated
aborted take off delayed
aborted take off improper
aborted take off not performed
aborted takeoff not performed
ac handling abrupt
ac handling improper
ac protective covering not used
aerobatics attempted
aerobatics improper
aerobatics intentional
aerobatics performed
air speed not maintained
air speed vr below
all available runway not used
altitude clearance inadequate
altitude clearance not maintained
altitude improper
altitude inadequate
altitude low
anti ice de ice system not used
bail out emergency ejection delayed
bail out emergency ejection intentional
buzzing intentional
buzzing performed
carburettor heat improper use of
carburettor heat not used
checklist not used
clearance inadequate
climb delayed
climb not performed
communication not maintained
communications not performed
compensation for wind conditions poor
cross wind component exceeded
descent premature
design stress limits of ac exceeded
dispatch procedure not followed
distance altitude inadequate
emergency equipment disregarded
emergency procedure delayed
emergency procedure not followed
emergency procedure not performed
emergency procedure simulated
engine shutdown intentional
engine shutdown not performed
engine shutdown performed
flight advisory disregarded
flight controls not corrected
flight into adverse weather attempted
flight into adverse weather continued
flight into adverse weather inadvertent
flight into adverse weather initiated
flight into adverse weather intentional
flight into adverse weather selected
flight to alternate destination delayed
flight to alternate destination not performed
formation flying attempted
formation flying misjudged
fuel management improper
fuel management inadequate
fuel supply inadequate
fuel supply not used
gear down and locked intentional
gear extension not performed
gear retraction not performed
gear retraction not selected
glider tow release delayed
glider tow release not performed
go-around attempted
go-around delayed
go around attempted
go around delayed
go around initiated
go around not performed
hazardous weather advisory disregarded
ice frost removal from ac not performed
ifr procedure not followed
improper decision
in-flight planning inadequate
in-flight planning/decision improper
in-flight planning/decision inadequate
in flight planning/decision inadequate
inflight briefing service not obtained
inflight planning decision delayed
inflight planning decision improper
inflight planning decision improper p2
inflight planning decision inaccurate
inflight planning decision inadequate
inflight planning decision intentional
inflight planning decision poor
inflight planning preparation poor
inflight weather advisory not attained
inflight weather avoid assistance not followed
inflight weather avoidance assistance delayed
inflight weather avoidance assistance not used
judgement poor
judgment improper
judgment poor
lift off premature
low altitude flight maneuver intentional
low altitude flight maneuver performed
low altitude flight/maneuver excessive
low altitude flight/maneuver performed
low pass intentional

low pass performed
lowering of flaps delayed
lowering of flaps excessive
lowering of flaps not performed
lowering of flaps performed
maneuver abrupt
maneuver attempted
maneuver delayed
maneuver excessive
maneuver improper
maneuver initiated
maneuver performed
maneuver to avoid obstruction intentional
maneuver to avoid obstructions not performed
meteorological service not obtained
misc eqp not used
missed approach delayed
missed approach not performed
op with known def in eqp performed
ostentatious display
performance data improper use of
planned approach improper
planned approach not followed
planned approach poor
planning decision improper
planning decision inadequate
planning decision poor
preflight briefing service disregarded
preflight briefing service not followed
preflight briefing service not obtained
preflight briefing service not used
procedure directives improper
procedure directives not followed
procedure directives not followed p2
propeller feathering performed
proper altitude exceeded
proper altitude not attained
proper altitude not maintained
proper altitude not selected
proper altitude not used
proper descent rate delayed
proper descent rate exceeded
pull up attempted
pull up delayed
pull up excessive
pull up performed
radar assistance to vfr ac disregarded
radar assistance to vfr not obtained
radar assistance to vfr not obtained p2
raising of flaps not performed
refuelling delayed
refuelling improper
refuelling inadequate
refuelling not performed
remedial action delayed
remedial action improper
remedial action inadequate
remedial action not performed
removal of control gust lock not performed
rotation abrupt
rotation premature
shoulder harness not used
stall intentional
stall performed
stall spin inadvertent
stall spin initiated
stall spin performed
taxi speed excessive
traffic advisory not issued
unsafe hazardous condition warning disregarded
unsafe/hazardous contidtion not identified
unsuitable terrain for take off landing selected
unsuitable terrain not obtained
unsuitable terrain or takeoff area selected
updating of recorded weather info not obtained
vfr flight into imc attempted
vfr into imc attempted
vfr into imc inadvertent
visual look out inadequate
weather evaluation disregarded
weather evaluation improper
weather evaluation inadequate
weather evaluation misjudged
weather evaluation not performed
weather evaluation poor
weather forecast disregarded
weather forecast not obtained
weather radar not used
wind information disregarded
wrong runway selected

APPENDIX H

DECISION ERROR FREQUENCIES

Decision Error Category	Frequency	Percent
Inflight Planning Improper	**187**	**25.5%**
Inflight planning decision improper	102	
Inflight planning decision poor	42	
Inflight planning decision inadequate	30	
Inflight planning decision delayed	4	
In-flight planning inadequate	1	
In-flight planning/decision improper	1	
In-flight planning/decision inadequate	1	
In flight planning/decision improper	1	
Inflight briefing service not obtained	1	
Inflight planning decision improper p2	1	
Inflight planning decision inaccurate	1	
Inflight planning decision intentional	1	
Inflight planning preparation poor	1	
Altitude/Clearance Improper	**70**	**9.5%**
Altitude inadequate	55	
Altitude improper	7	
Altitude low	5	
Altitude clearance inadequate	2	
Altitude clearance not maintained	1	
Judgment Poor	**49**	**6.7%**
Judgment poor	48	
Judgment improper	1	
Aborted Take Off or Landing	**35**	**4.8%**
Aborted take off not performed	16	
Aborted landing delayed	10	
Aborted take off delayed	4	
Abort above V1 performed	1	
Abort not performed	1	
Aborted landing initiated	1	
Aborted take off improper	1	
Aborted takeoff not performed	1	
Weather Evaluation Inadequate	**31**	**4.2%**
Weather evaluation inadequate	8	
Weather forecast disregarded	5	
Weather evaluation improper	4	
Weather evaluation misjudged	4	
Weather evaluation poor	4	
Weather forecast not obtained	2	
Weather evaluation disregarded	1	
Weather evaluation not performed	1	
Weather radar not used	1	
Wind information disregarded	1	

Decision Error Category	Frequency	Percent
Planning Decision Error	**29**	**4.0%**
Planning decision improper	26	
Planning decision poor	2	
Planning decision inadequate	1	
Refueling Error	**21**	**2.9%**
Refueling not performed	17	
Refueling improper	2	
Refueling delayed	1	
Refueling inadequate	1	
Low Altitude Flight/Maneuver	**20**	**2.7%**
Low altitude flight maneuver performed	11	
Low altitude flight maneuver intentional	3	
Low altitude flight/maneuver performed	2	
Low pass performed	2	
Low altitude flight/maneuver excessive	1	
Low pass intentional	1	
Preflight Briefing Service Not Obtained/Followed	**20**	**2.7%**
Preflight briefing service disregarded	7	
Preflight briefing service not used	7	
Preflight briefing service not obtained	5	
Preflight briefing service not followed	1	
Remedial Action Improper	**17**	**2.3%**
Remedial action delayed	11	
Remedial action not performed	3	
Remedial action inadequate	2	
Remedial action improper	1	

APPENDIX I

SEMINAL DECISION ERROR FREQUENCIES

Seminal Decision Error Categories	Frequency	Percent
Inflight Planning Improper	**93**	**24.0%**
Inflight planning decision improper	63	
Inflight planning decision poor	16	
Inflight planning decision inadequate	11	
Inflight planning inadequate	1	
Inflight planning decision delayed	1	
Inflight planning decision intentional	1	
Judgment Poor	**35**	**9.0%**
Judgment poor	34	
Judgment improper	1	
Planning Decision Error	**26**	**6.7%**
Planning decision improper	23	
Planning decision poor	2	
Planning decision inadequate	1	
Altitude/Clearance Improper	**21**	**5.4%**
Altitude inadequate	13	
Altitude improper	3	
Altitude low	3	
Altitude clearance inadequate	1	
Altitude clearance not maintained	1	
Weather Evaluation Inadequate	**19**	**4.9%**
Weather forecast disregarded	5	
Weather evaluation inadequate	4	
Weather evaluation improper	3	
Weather evaluation misjudged	2	
Weather evaluation disregarded	1	
Weather evaluation not performed	1	
Weather forecast not obtained	1	
Weather radar not used	1	
Wind information disregarded	1	

APPENDIX J

PERCEPTUAL ERROR CODES

aerobatics misjudged
air speed misjudged
altitude clearance misjudged
altitude misjudged
clearance inadequate
clearance misjudged
clearance not maintained
clearance not obtained maintained
descent misjudged
distance altitude misjudged
distance misjudged
distance speed misjudged
distance/altitude misjudged
emergency procedure misjudged
flare misjudged
judgment poor
level off misjudged
low altitude flight manuever misjudged
low altitude flight/maneuver misjudged
maneuver misjudged
navaid signal misjudged
proper touch down misjudged
pull up misjudged
SD
SD unqualified person
vfr into imc inadvertent
visual aural detection
visual aural perception
visual aural perception p2
visual illusion
visual look out inadequate
weather evaluation misjudged
wind information misjudged

APPENDIX K

PERCEPTUAL ERROR FREQUENCIES

Perceptual Error Category	Frequency	Percent
Visual/Aural Detection/Perception	**34**	**29.8%**
Visual aural perception	18	
Visual aural detection	10	
Visual illusion	4	
Visual aural perception p2	1	
Visual look out inadequate	1	
Distance/Descent Misjudged	**20**	**17.5%**
Distance misjudged	7	
Distance altitude misjudged	5	
Distance speed misjudged	5	
Descent misjudged	1	
Distance/altitude misjudged	1	
Altitude Misjudged	**18**	**15.8%**
Altitude misjudged	16	
Altitude clearance misjudged	2	
Clearance (From Object or Aircraft) Not Maintained	**18**	**15.8%**
Clearance misjudged	11	
Clearance not maintained	5	
Clearance inadequate	1	
Clearance not obtained/maintained	1	
Maneuver/Procedure Misjudged	**12**	**10.5%**
Flare misjudged	5	
Pull up misjudged	2	
Aerobatics misjudged	1	
Emergency procedure misjudged	1	
Level off misjudged	1	
Maneuver misjudged	1	
Proper touch down misjudged	1	
Spatial Disorientation	**5**	**4.4%**
Spatial disorientation	4	
Spatial disorientation unqualified person	1	
Low Altitude Flight Maneuver Misjudged	**2**	**1.8%**
Low altitude flight maneuver misjudged	1	
Low altitude flight/maneuver misjudged	1	
Wind/Weather Information Misjudged	**2**	**1.8%**
Weather evaluation misjudged	1	
Wind information misjudged	1	
Judgment Poor	**1**	**0.9%**
VFR into IMC Inadvertent	**1**	**0.9%**

APPENDIX L

SEMINAL PERCEPTUAL ERROR FREQUENCIES

Seminal Perceptual Error Category	Frequency	Percent
Distance/Descent Misjudged	**16**	**32.0%**
Distance misjudged	6	
Distance altitude misjudged	6	
Distance speed misjudged	3	
Descent misjudged	1	
Clearance (From Object or Aircraft) Not Maintained	**13**	**26.0%**
Clearance misjudged	8	
Clearance not maintained	4	
Clearance not obtained/maintained	1	
Maneuver Misjudged	**11**	**22.0%**
Flare misjudged	5	
Low altitude flight maneuver misjudged	2	
Aerobatics misjudged	1	
Maneuver misjudged	1	
Proper touch down point misjudged	1	
Pull up misjudged	1	
Altitude Misjudged	**8**	**16.0%**
Altitude misjudged	7	
Altitude clearance misjudged	1	